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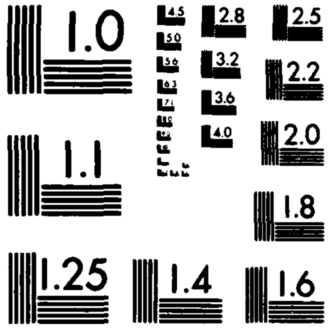

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SAMPLE PROBLEMS FOR STAGSC-1

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FLIGHT DYNAMICS LABORATORY
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This technical report has been reviewed and is approved for publication.

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Sample problems and clarification for the STAGSC-1 computer program are presented. The report is directed toward the beginning user of STAGSC-1, and possibly the beginner in structural and/or finite element analysis.

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PREFACE

This report was prepared as a supplement to the STAGSC-1 User's Manual. It presents clarifications and sample problems and is directed toward the beginning user of STAGSC-1, and possibly the beginner in structural and/or finite element analysis.

The report was prepared by the Aerospace Structures Information and Analysis Center, which is operated for the Flight Dynamics Laboratory, Air Force Wright Aeronautical Laboratories, by Anamet Laboratories, Inc., under Contract No. F33615-81-C-3201, as Problem No. 414. Contract F33615-81-C-3201 was initiated under Project 2401, "Structures and Dynamics," Task 240102, "Design and Analysis Methods for Flight Vehicles." The contract was administered by Mr. J. R. Johnson, AFWAL/FIBRA, Wright-Patterson AFB, Ohio. Dr. N. S. Khot provided technical assistance for this particular effort.

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1.0 OVERVIEW AND SUMMARY OF USER'S MANUAL

1.1 INTRODUCTION AND GENERAL COMMENTS

This report was prepared as an introduction to using the STAGSC-1 computer program. It is not an attempt to rewrite the current STAGSC-1 User's Manual [1]; however, as with any manual, there are certain aspects which sometimes are not easy to understand. This report is especially addressed to the user that might not be as experienced as the STAGSC-1 manual presumes.

Clarification of selected input data cards which this reviewer found somewhat confusing are covered in Section 1.2. Section 1.3 of this report discusses selected output messages, nomenclature, and options which will aid in understanding the STAGSC-1 output. Section 2.0, which comprises the bulk of this report, is an assembly of various sample runs. The input data for the sample problems are included in the main text of this report. [illegible]; buckling; [illegible]; stiffeners, nonlinear analysis

1.1.1 Use of This Report

This report is aimed at the beginning user of STAGSC-1 and possibly the beginner at structural and/or finite element analysis. The following procedure for understanding the use of STAGSC-1 is recommended. First, review this report without reading in detail. Especially, review the sample problems and input data format presented in Section 2. Next read Sections 1, 2 and the first few pages of Section 3 from the STAGSC-1 User's Manual [1].

Next, examine the first example (Section 2.1.1) of this report and look up any card in Section 3 of the User's Manual which is not understood. If the explanation in the User's Manual seems confusing, check Section 1.3 of this report to see if additional clarification of the card has been covered. Finally, run the sample problem and examine the output. Refer to Sections 1.3.1, 1.3.2, 2.1.6, and Appendix E if questions concerning the output arise. If the reader is interested in the complete ouput of the ten sample problems, he should contact AFWAL/FIBRA.

After running through a sample problem, one can proceed in whatever fashion suits one best. The purpose of the additional samples in Section 2 is to illustrate various capabilities of STAGSC-1.

It should be mentioned that although the STAGSC-1 User's Manual does not contain an index as such, the mini-manual (Section 9) seems to serve the same purpose. It is very useful for locating the proper cards without rummaging through the voluminous data card descriptions (Section 3).

1.1.2 Overview of the STAGSC-1 Program

The STAGSC-1 program originated as a finite-difference based structural analysis program. Eventually, it was converted to the present configuration which is entirely finite element based. However, some of the nomenclature which was used in the generation of meshes and grids was retained. The terms "rows" and "columns" are examples.

The STAGSC-1 computer program is comprised of four modules: STAGS1; STAGS2; POSTP; and STAPL. The STAGS1 module is a preprocessing module which performes model generation, and various preliminary calculations. Execution of this module typically precedes the execution of the other modules. The STAGS2 module performs the bulk of the numerical computations associated with finite element analysis. STAGS2 module performs matrix decomposition, linear and nonlinear stress analyses, eigenvalue analyses, etc. The POSTP module is a postprocessing module for determining secondary solutions from previously calculated displacement solutions which have been saved on the restart file TAPE22. The STAPL module is a module for plotting undeformed and deformed geometries and solution contour plots. This manual is directed toward the input and output data associated with the STAGS1 and STAGS2 modules. For information on the use of POSTP and STAPL, the reader is referred to Section 5 of [1].

STAGS-1 employs unique "substructures" known as shell units and element units. A shell unit is a collection of finite elements and nodes which may be defined using standard shell shapes or with user-written subroutines. The user defines a shell unit by specifying limited data concerning the shell and letting STAGSC-1 generate the actual internal nodes and elements. The element unit is more like a regular finite element mesh. Only one element unit may be specified, and it is defined by node locations and element connectivities as in most standard finite element codes. The one element unit can be used to specify any number of finite elements and nodes, their locations and connectivities to other shell units being arbitrary. In the user's manual the "A through R" cards are concerned mostly with defining shell units, while the "S through V" cards are used for defining element units. There are, however, certain cards in the "A through R" sequence which must always be present, regardless of whether shell or element units are being employed. Paging through the user's manual will allow identification of these cards.

Another apparently unique aspect of STAGSC-1 (although it is mostly terminology) is the use of "surface coordinates." These are discussed in Section 2 and are referred to in Figure 3.9 of [1]. Surface coordinates are simply alternative coordinates used to describe a surface. By definition, all surfaces can be described by two independent coordinates. These are denoted "surface coordinates" in STAGS. For example, in normal nomenclature, a cylinder can be described by three Cartesian coordinates, x, y, and z, with an equation relating them, that is:

$$x^2 + y^2 + z^2 = R^2$$

Hence there are only two independent variables, since R is constant. Alternately, the surface may be described by two independent variables, z and θ through use of the following equations:

$x = R \cos \theta$

$y = R \sin \theta$

z = same z as before

Here z and θ would be called the "surface coordinates." For other examples see Figure 3.9 [1].

1.2 CLARIFICATION OF SELECTED INPUT DATA CARDS

This Section will present input data cards which were judged to require some additional explanation to that presented in the User's Manual. Not all cards are covered; only those more commonly used or specifically requested by AFWAL/FIBR are discussed. If the explanation in the User's Manual was found sufficient, then the card will not be discussed.

Card	Variable	Comments
(B-1)	IPOSTO	Only used for plots, data written to FORTRAN unit 21
	IPOST1	If IPOST1 = 0 saves last 3 displacement vectors on unit 22 If IPOST1 = I saves last I displacement vectors on unit 22 (As with any data saved during the run, the user is required to furnish the proper job control language (JCL) in order to save the specific files)
(B-2)	NIMPFS	Tape or unit 25 is the same as unit 22 saved from a previous buckling run. It is recommended that imperfection amplitudes be on the order of one percent of the panel thickness. Note that only local w-displacements for each shell unit are used to define the imperfection shape. The total imperfection is printed in the STAGS1 output.
(B-3)	NTAP	This parameter indicates the number of user parameters required by the user-written routines if used. See (L-1) card.

(B-5) WIMPFA — There are NIMPFS terms on this record which define the buckling mode amplitudes used for the initial imperfection. Note that the buckling modes are normalized to the maximum value in the eigenvector and usually contain a 1.0 value.

(C-1) STLD(I) — The base load is defined via "Q" cards. Two different base load systems may be specified, load system A and load system B. For linear analysis, the total load on the structure is given by:

$$P_{lin} = \text{STLD(1)* (Base load for system A)} + \text{STLD(2)* (Base load for system B)}$$

For buckling analysis, load system B is assumed to remain constant. The total load at buckling is:

$$P_{buc} = \lambda\text{*STLD(1)*(Base load for system A)} + \text{STLD(2)*(Base load for system B)}$$

Where λ is the eigenvalue found from the buckling analysis. For nonlinear analysis, first a linear analysis is performed using P_{lin} from above. Next a nonlinear analysis is performed using P_{lin} from above; this is called step 1. For step 2, a nonlinear analysis is performed using the total load given by:

$$P_{non} = \text{(STLD(1)+STEP(1))*(Base load for sys A)} + \text{(STLD(2)+STEP(2))*(Base load for sys B)}$$

The remaining load steps would then normally use, say, (STLD(I) + STEP(I) + ... STEP(I)) as the load multiplier unless the STEP(I) is automatically halved or doubled by STAGSC-1 (see Section 6 [1] for a discussion of this). Here I = 1 for load system A, and I = 2 for load system B.

If the postbuckling response is being calculated, the starting load should be under the linear bifurcation buckling load (e.g., STLD(1) = .5 * Critical Buckling Load) and the load step size such that 2 or 3 steps are required to reach the buckling load (e.g., STEP(1) = .2 * Critical Buckling Load). Additionally, it is recommended that STLD(I) and STEP(I) be chosen such that (STLD(I) + STEP(I) +...) equal about 1.0 at the estimated critical buckling load. This is also the recommended procedure when using the path length as an independent parameter (see NSTRAT of card (D-1)). Note that STEP(1) and STEP(2) have to be greater than or equal to zero. Negative load steps are not allowed.

(D-1)	ISTART	For a new case or for using the POSTP post-processor, ISTART must be set to zero.
	NCUT	For new users, a value of four is recommended. As the user gains some experience and confidenece in nonlinear analysis this value may be changed
	NEWT	Same comment as for NCUT. If it is equal to -20, a true Newton-Raphson method is used (update the stiffness matrix on every iteration.)
	NSTRAT	This parameter controls the solution strategy used in the analysis. If it is positive, then a modified Newton-Raphson method is used. If it is equal to -1, the Riks method will be used. Traditionally, the postbuckling response of a structure has been obtained analytically using the modified Newton-Raphson solution procedure of the STAGSC-1 computer code by incrementing a load parameter and solving for the corresponding solution vector. Structural instability is indicated by a failure of the modified Newton-Raphson solution procedure to converge, even with a very small load step, or by a change in sign of the determinant of the tangent stiffness matrix. The problems associated with the use of a load parameter as an independent parameter are related to solution prediction beyond a limit point and to ill-conditioning of the tangent stiffness matrix in the neighborhood of a limit point. The Riks method based on controlling an equilibrium-path-arc-length parameter instead of the traditional load parameter has been introduced into the STAGSC-1 computer code. The Riks method eliminates one singularity in the tangent stiffness matrix at critical points that causes major computational difficulties. Using the Riks method, solutions along the unstable equilibrium path of the postbuckling response can be predicted provided only one eigenvector is dominating the response (i.e., there is no modal interaction or change in buckle pattern). As implemented in the

STAGSC-1 computer code, the Riks method may require frequent updating and refactorization of the tangent stiffness matrix to follow the unstable equilibrium path if the eigenvalues of the tangent stiffness matrix are closely spaced. The implementation of the Riks method is such that the load step size will not increase after it has been cut in order to trace an unstable equilibrium path. The Riks method is very useful but requires the analyst to carefully watch the progress of the analysis.

DELX — This parameter often has to be changed on restarts in order to allow a nonlinear solution to proceed. If this error tolerance is too large, and the stiffness matrix is becoming nearly singular due to a buckling phenomenon, then the small errors accumulated tend to cause numerical problems with the stiffness matrix unless DELX is lowered.

WUND — The use of this factor was not discussed in the User's Manual. WUND is an overrelaxation factor that the program changes internally. It is recommended that the program be allowed to select its own value (i.e., do not input a value for WUND).

(D-2) — Note that if IPRINT is set to a value of 1 or 3, the buckling modes are not written to TAPE22.

(G-2) — Partial compatibility contraints are defined via a base freedom and a slave freedom that is equated to the base freedom. These constraints are shown in the computational degree-of-freedom table. Note that these constraints apply only to the nodal freedoms and not to the variation between nodes (i.e., not enforced at midside nodal d.o.f.).

(G-4) CC(I) — The coefficients used for the constraints should be of the order one because of how the terms of the stiffness matrix are scaled during decomposition.

(I-2) — Be careful in defining material properties. The nomenclature used in STAGSC-1 is not the same as used in many books on composites. A check is that if E1 > E2 then V21 will be the larger Poisson ratio, i.e., V21>V12.

(J-1)		The "bar" axis used in defining the section properties will be oriented (using the "O" cards) with respect to the "prime" axis defined at each row-column intersection or "node" (See Figure 3 [1]).
	SCY	For an example of calculating these factors see Section 2.3.1.
(K-1)		Note that a maximum value of NLAY is 50.
(M-2A)		All angles are in degrees. PROP(5) for ISHELL=5 (cylinder) is R not R^2.
(N)		These cards enable a user to define irregular grids, specialized grids, or uniform grids.
(Q-3)	LT	Irrelevant for initial conditions but cannot be zero.
(R-1)		This card defines most of the output information that is desired. However, additional stress output control can be obtained with cards (K-2) for walls and some of the stiffener or ring cards (J-1).

1.3 OUTPUT AND CLARIFICATION OF SELECTED OUTPUT INFORMATION

This section discusses interpretation of selected output information from the STAGSC-1 program. Information judged evident or obvious has been omitted. The emphasis here is to discuss topics that the user of other finite element codes may not be familiar with and also to present a few self-checks for the inexperienced user.

A sample input job control language (JCL) to run the VAX version of STAGSC-1 is presented in Figure 1. The use of various FORTRAN units is indicated. The preprocessing program which must be run at least once for each new data deck is STAGS1. If desired, the output from STAGS1 may be saved from FORTRAN unit 2 and used in subsequent restarts. This was not attempted for this report since, generally, the preprocessing was inexpensive.

As shown in Figure 1, after running STAGS1, STAGS2 is run. STAGS2 is the actual finite element solution procedure. The output from each program is now discussed.

```
$
$! PROCEDURE TO EXECUTE STAGS1 AND STAGS2
$
$ SET DEF (.STAGS)
$ SET VERIFY
$
$! COMMENTS - JOBONE.INP = INPUT DATA FILE
$!            JOBONE.RST = FILE TO SAVE DISPS FOR RESTART
$!            OUTPUT WILL BE SENT TO SYSTEM PRINTER
$
$ ASSIGN JOBONE.INP FOR005
$ RUN (STAGSC1)STAGS1.EXE
$ ASSIGN JOBONE.RST FOR020
$ RUN (STAGSC1)STAGS2.EXE
```

Figure 1 Job Control Language (JCL) for Executing STAGSC-1 on the VAX

1.3.1 Preprocessing (STAGS1) Output

This output is generally not dependent upon the type of analysis to be performed (linear, buckling, nonlinear, etc.). Most of the output from this phase of solution is self-explanatory, but the following comments are included for the beginner:

(1) When preparing the input data deck, put the appropriate card identification ((B-1) etc.) as a comment to aid in debugging and future reference.

(2) Look over the "INPUT DATA CARDS" echo for any obvious mistakes.

(3) Don't worry about computer memory or timing information unless problems occur or timing estimates seem very large.

(4) Check the mesh SURFACE COORDINATES vs. the GLOBAL CARTESIAN COORDINATES to see if they make sense.

(5) Check ring and stringer locations.

(6) Check constitutive matrices to see if they appear to be the right order of magnitude.

(7) Check loads data.

(8) Note the COMPUTATIONAL DOF ASSIGNMENTS for future reference (Section 1.3.2).

Generally, the best check of a model is to run a simple case where expected results can be calculated by hand. In this case the output from STAGS2 (solution phase) might be checked first. The output from STAGS1 might then help to determine possible data errors. However, a mistake in the input will sometimes have little effect on the output for your test problem, but will then cause problems when the real problem is run. Hence, it is recommended that the output from STAGS1 be given at least a cursory check before the model is considered correct.

1.3.2 Solution (STAGS2) Output

As stated above, the best check of a model is a simple test case for which known solutions can be independently calculated. For complicated structures for which a hand calculation may be difficult to obtain, there is at least one test case that can always be run.

First, a set of boundary conditions is picked that adequately prevents rigid body motion of the structure. Next, displacements are prescribed for those boundary points (such as a unit displacement). The output should show that all displacements of the structure are equal to the prescribed boundary displacements. This may be generally run for six separate load cases, each load case prescribing a unit displacement or rotation for each of the coordinate directions.

With reference to the output from STAGS2, the following checks and comments apply:

(1) Check the displacement output to ensure that reasonable values are being obtained and that the proper boundary conditions have been enforced. The displacements for the linear solution are used to determine initial stresses for a buckling analysis. These displacements are also used as initial starting vectors in a nonlinear analysis.

(2) Equilibrium forces should be very small numbers except for points where boundary conditions or applied loads exist.

(3) Force resultants are either in units of force/length or moment/length.

(4) Stresses in composite plates depend upon the ply that is being examined. Strains often produce more readily-interpreted information.

(5) The MODE DISPLACEMENTS only give the pattern of the buckled structure but yield no information as to the actual displacements that occur after buckling; a nonlinear analysis is required for this. The modeshape is usually normalized to its maximum value. Check these displacement patterns to see if reasonable results have been obtained.

(6) In nonlinear analysis, often convergence during the first few steps will not occur if the first load step is too large. If this is suspected, examine the step 0 (linear) displacements and the step 1 (nonlinear) displacements. They should be approximately equal. If they are not, the first load increment being used may be too large and cause inaccurate solutions later on. The inaccurate solutions may cause nonconvergence later in the analysis.

(7) Various elements have additional degrees of freedom associated with them. These additional degrees of freedom are discussed briefly in Section 6 of [1] and in slightly more detail in Section 4.3 of [2]. The example runs in this case used the 411 element which prints out an additional rotation labeled RW2. This is a measure of the individual elements out-of-plane rotation (see Table 6.3.1 of [1]).

Diagnostic messages from STAGSC-1 are generally adequate for debugging a model although often one has to hunt through voluminous output to find them. Section 7 of [1] should be read since it explains most of the non-obvious messages. One comment which applies to most finite element codes, including STAGSC-1, will now be discussed.

Often a great confusion for inexperienced finite element code users stems from messages concerning singular or nearly singular stiffness matrices. One output from STAGSC-1 is the determinant of the stiffness matrix, sometimes accompanied by comments as to whether the matrix is ill-conditioned or not. The determinant of the stiffness matrix is computed as follows. The stiffness matrix is decomposed (factored) into the form:

$$K = U^T D\ U$$

where

U is an upper triangular matrix with 1's on the diagonal.
D is a diagonal matrix.

Therefore, det(K)=det(D), which is just the diagonal terms of D multiplied together. Therefore det(K) depends on the size of K and will be very different if a 100 × 100 matrix or a 10,000 × 10,000 matrix is being decomposed. Therefore, det(K) does give a measure of the singularity of K but not really a very good one. Often when a singularity occurs, STAGSC-1 also prints out the smallest diagonal term after factorization. This is the smallest element of the D matrix above. By noting the equation number for the smallest diagonal term and cross-referencing to the COMPUTATIONAL DOF ASSIGNMENTS (Section 1.3), the row-column location of a potential problem area may be found. STAGSC-1 has an option to remove singularities in the stiffness matrix which basically constrains that degree of freedom to zero. This option is appropriate in most situations, but a judgment should be made to ascertain whether the other displacements and EQUILIBRIUM FORCE BALANCES ((2) above) are reasonable before accepting the validity of the results.

2.0 SAMPLE PROBLEMS INPUT, OUTPUT AND INTERPRETATION

In this section various sample problems are presented. The problems are presented in order of complexity. The problems include flat and curved plates, stiffened and unstiffened, linear static, buckling and nonlinear analysis.

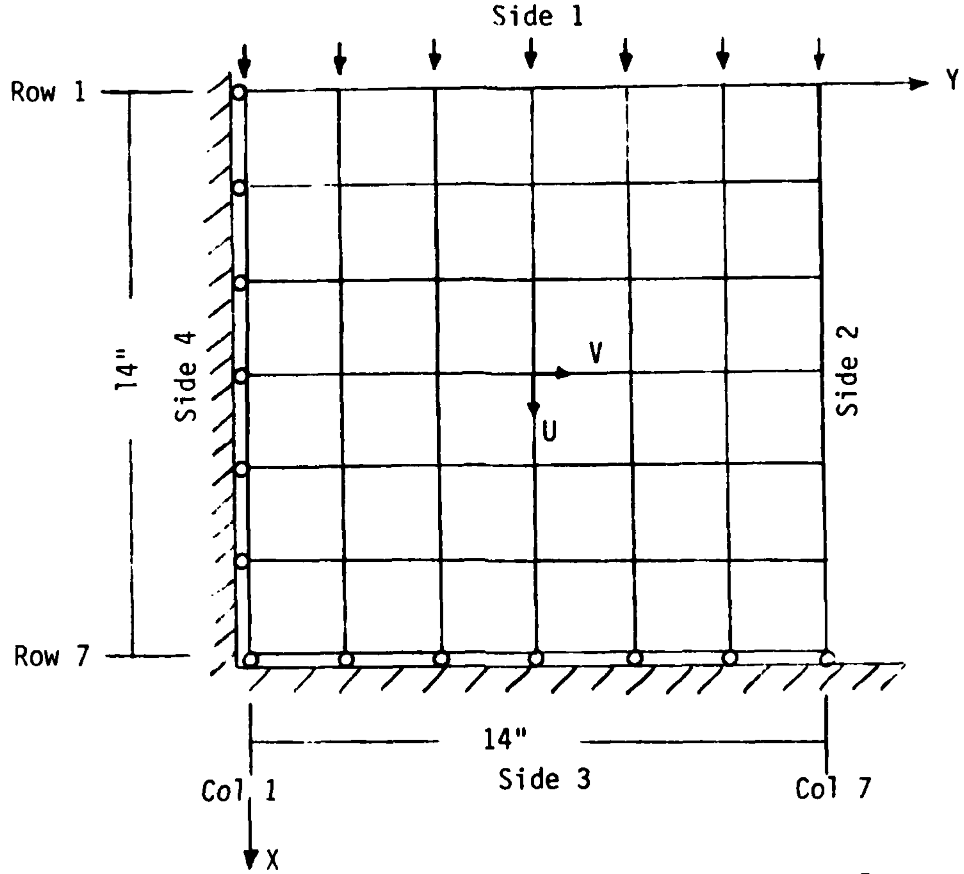
In all sample problems the 411 element was used. Selecting the best element often depends on the problem. The 411 element was chosen here based partly on comments in Section 6.0 of Reference [2] and partly on previous experience. Since the 411 element has been found to perform acceptably for most problems, it is recommended here for the beginner. Once experience has been gained, the user may experiment with other elements in order to determine their relative merits. For more detailed studies and discussions of STAGSC-1 elements the reader is referred to References [2] and [6].

2.1 FLAT COMPOSITE PLATE

This section describes four sample runs performed on the flat square plate of Figure 2. The dimensions, layup and loading are shown in Figure 2. The boundary conditions for the plate are "classical" simple supports. The inplane (X and Y) translational boundary conditions are shown in Figure 2. The input and output from the four sample runs will now be described.

2.1.1 Input for Linear Statics (KNCOMPO)

Figure 3 shows the input for a linear statics run. The run is given the label KNCOMPO for future reference and for cross-referencing to the computer printout. As can be seen, appropriate comments have been placed in the input listing of Figure 3 so that it is fairly self-explanatory. All cards in the input have been identified as to their type using the STAGS nomenclature (B-1), (C-1) etc. For a full explanation of any particular card type, see the appropriate data card (Section 3) of the STAGS User's Manual [1].



LAYUP = $[\pm 45/90/0]_s$

Theoretical Buckling Load:

N_x^{cr} = 15.66 lb/in

m = 1 *

STAGS:

N_x^{cr} = 15.03 (KNCOMP1)

E_L = 19.6×10^6 psi

E_T = 1.89×10^6 psi

G_{LT} = 0.93×10^6 psi

ν_{LT} = 0.38 or ν_{LT} = 0.0366

t_{layer} = 0.0056"

*Buckling of Bars, Plates and Shells, Brush & Almroth, p. 108, McGraw-Hill, 1975.

Figure 2 Model of Flat Plate Used in KNCOMP Series of Runs

```
KNCOMPO  -  KNIGHT, LINEAR STATICS OF COMPOSITE PLATE, 7 X 7 MESH
0 0 0 0 0 0 1  $    (B-1) - LINEAR BUCKLING, FULL PRINT OUT
1/1 0 1  $          (B-2,3)- NO. SHELL UNITS=1/ NO. MATLS=1 , NO. SHELL WALLS=1
1.    $             (C-1) - LOAD FACTOR = 1.
7 7$                (F-1) - MESH = 7 X 7, I.E. 7 ROWS AND 7 COLUMNS
$
1/19.6+6 .0366 .93+6 0. 0. 1.89+6  $ (I-1,2) - MATERIAL ID/ MATERIAL PROPERTIES
$
1 1 8  $            (K-1) - WALL ID 1, GEN. LAYERED, 8 LAYERS
1 .0056  45. 1    $ (K-2) - MATL ID=1, THICK=.0056, ANGLE=45., PRINT STRESS
1 .0056 -45.      $
1 .0056  90.      $                REPEAT FOR EACH LAYER
1 .0056   0.
1 .0056   0.
1 .0056  90.
1 .0056 -45.
1 .0056  45. 1
$
2/0. 14. 0. 14./1  $(M-1,2A,5) RECTANGLE/ 14. X 14. PLATE/ WALL ID = 1
411 0 0 0 0 1  $     (N-1) - STANDARD MESH ELEM TYPE=411, REDUCED INTEGRATION
$
0 0 0 0       $       (P-1) - SPECIFY ALL BC S ON (P-2) CARDS
110 011       $       (P-2) - SIDE 1
110 101       $                    2
010 011       $                    3
100 101       $                    4 - RESTRAIN RIGID BODY MOTION IN V DIR
$
1/ 1 1        $  (Q-1,2)- 1 LOAD SYSTEM/ LOAD SYS A, NO. OF (Q-3) RECORDS=1
1.  2  1  1  $   (Q-3) - SIDE 1 LOAD MAG=-1., LINE LOAD ON ROW, U DIR, ROW 1
$ 0. -1  6    $   (Q-3) - ENFORCE 0 RW ROTATION FOR ALL NODES
$
1 1 0 0 0 1 $ (R-1) - OUTPUT CONTROL PRINT DISP, STRESS RESLNTS, POINT FORCES
```

add in (D-2) and (D-3) cards for KNCOMP1 (Buckling Analysis)

Figure 3   Input for Linear Statics

The first card must always be a comment card. The second card is called the Analysis Type Definition Record and is denoted as card (B-1) in the STAGS User's Manual. The "B" type cards define overall properties of the model such as how many different materials are being used, etc. The load factor of 1.0 on the (C-1) card is the factor that multiplies the load system that is later defined on the "Q" cards. Material properties are then defined on the "I" cards. The "K" cards define the number of layers and the layup of each layer for each wall. They are repeated if more than one wall ID exists (No. of shell wall is given on (B-3)). The "M" cards define the shell type (rectangular plate in this example), the shell dimensions, and the associated wall ID. The "N" cards define what element type is to be used and whether reduced or standard integration is to be used (reduced integration is generally recommended). The "P" cards define the boundary conditions; the "Q" cards define the loads; and finally, the "R" card defines output options and control.

The changes to be made to "KNCOMP0" in order to perform the next analysis, which is a buckling analysis, are noted in Figure 3. Thus, the only modification required in the present example is to change the (B-1) card and add in two additional cards (D-2) and (D-3) which will be explained under the linear buckling input description.

2.1.2 Linear Buckling Analysis (KNCOMP1)

Figure 4 presents the input for a linear buckling (or linear bifurcation) analysis. The linear buckling analysis differs from the nonlinear buckling analysis in that the pre-stress state for the linear analysis is obtained from a linear stress analysis. See Reference [1] or [3] for further details concerning these differences. As can be seen, most of the input cards for the buckling analysis are the same as the linear stress analysis. The main difference is the inclusion of the (D-2) and (D-3) cards and the first entry on the (B-1) card. An abbreviated explanation of these cards is included in Figure 4. Additional information

```
KNCOMP1  -  KNIGHT, COMPRESSION BUCKLING OF COMPOSITE PLATE, 7 x 7 MESH
1 0 0 0 0 0 1  $    (B-1) - LINEAR BUCKLING, FULL PRINT OUT
1/1 0 1  $         (B-2,3)- NO. SHELL UNITS=1/ NO. MATLS=1 , NO. SHELL WALLS=1
1.   $             (C-1) - LOAD FACTOR = 1.
1 0 500/2  $       (D-2,3)- 1 EIGENVALUE CLUSTER, 500 CP SEC MAX/ 2 EIGENVECS
7 7$               (F-1) - MESH = 7 X 7, I.E. 7 ROWS AND 7 COLUMNS
$
1/19.6+6 .0366 .93+6 0. 0. 1.89+6  $ (I-1,2) - MATERIAL ID/ MATERIAL PROPERTIES
$
1 1 8  $            (K-1) - WALL ID 1, GEN. LAYERED, 8 LAYERS
1 .0056  45. 1   $ (K-2) - MATL ID=1, THICK=.0056, ANGLE=45., PRINT STRESS
1 .0056 -45.     $
1 .0056  90.     $              REPEAT FOR EACH LAYER
1 .0056   0.
1 .0056   0.
1 .0056  90.
1 .0056 -45.
1 .0056  45. 1
$
2/0. 14. 0. 14./1  $(M-1,2A,5) RECTANGLE/ 14. X 14. PLATE/ WALL ID = 1
411 0 0 0 0 1  $    (N-1) - STANDARD MESH ELEM TYPE=411, REDUCED INTEGRATION
$
0 0 0 0      $      (P-1) - SPECIFY ALL BC S ON OP-2) CARDS
110 011      $      (P-2) - SIDE 1
110 101      $                   2
010 011      $                   3
100 101      $                   4 - RESTRAIN RIGID BODY MOTION IN V DIR
$
1/ 1 1       $  (Q-1,2)- 1 LOAD SYSTEM/ LOAD SYS A, NO. OF (Q-3) RECORDS=1
1. 2 1 1  $    (Q-3) - SIDE 1 LOAD MAG=-1., LINE LOAD ON ROW, U DIR, ROW 1
$ 0. -1  6    $   (Q-3) - ENFORCE 0 RW ROTATION FOR ALL NODES
$
1 1 0 0 0 1 $ (R-1) - OUTPUT CONTROL PRINT DISP, STRESS RESLNTS, POINT FORCES
```

Figure 4   Input for Linear Buckling Analysis may be found in Section 1.2 and in the STAGS User's Manual. The circled items in Figure 4 indicate modifications to be made for changing to a nonlinear analysis.

2.1.3 Nonlinear Analysis, Triggering Load Included (KNCOMP3)

Figure 5 shows the input for a nonlinear static analysis of the previously described plate. Compared to Figure 4, the (B-1) card is changed to select the nonlinear analysis instead of the buckling analysis. The (D-2) and (D-3) cards have been removed since they only apply to buckling analysis, and the D-1 card was inserted. The (C-1) card has been modified so that the initial load factor is 1.0, the increment in load is 1.0 times the initial load, and the maximum load factor is 20. The (R-1) card was changed although this was not necessary. The modification of the (R-1) card was to print stress resultants every other step as opposed to every step. Figure 5 also includes a load used to trigger the initial buckling mode of the flat plate being analyzed. From the linear buckling analysis (or a hand analysis in this case), the initial buckling mode may be determined. Additional (Q-2) and (Q-3) cards were then added to apply a small force (.001 lbs), normal to, and at the center of the plate. Also, the (Q-1) card had to be modified to allow two loading systems, and the (C-1) card was also modified. As can be seen, the (C-1) card applies load system A in the same manner as before. The B load system however is "frozen" at its initial load (max load factor on (C-1) for load system B = 1). The output from this analysis, to be discussed in 2.1.5, shows that the anticipated result was obtained.

2.1.4 Nonlinear Analysis, Displacement-Controlled (KNCOMP4)

Figure 6 shows the input cards which now allow the load to be applied in terms of end-shortening or end-displacement of side 1 of Figure 2. As can be seen from Figure 5, the only modification required was that of the first (Q-3) record. The new (Q-3) now specifies an end-displacement of 5.0×10^{-5} inches

```
KNCOMP3 -  KNIGHT, COMP BUCK OF COMP PLATE, 7 x 7 MESH, W. TRIGGERING LOAD
3 0 0 0 0 0 1  $    (B-1) - NONLINEAR , FULL PRINT OUT
1/1 0 1  $         (B-2,3)- NO. SHELL UNITS=1/ NC. MATLS=1 , NC. SHELL WALLS=1
1. 1. 20. 1. 1. 1. $ (C-1) - LOAD FACTOR = 1. , INCREM=1., MAX = 20.
0 750 3 10 $        (D-1) - NEW CASE, 750 CP SEC MAX, 3 LOAD CUTS, 10 REFACTRS
7 7$                (F-1) - MESH = 7 x 7, I.E. 7 ROWS AND 7 COLUMNS
$
1/19.6+6 .0366 .93+6 0. 0. 1.89+6  $ (I-1,2) - MATERIAL ID/ MATERIAL PROPERTIES
$
1 1 8  $            (K-1) - WALL ID 1, GEN. LAYERED, 8 LAYERS
1 .0056  45. 1    $ (K-2) - MATL ID=1, THICK=.0056, ANGLE=45., PRINT STRESS
1 .0056 -45.      $
1 .0056  90.      $               REPEAT FOR EACH LAYER
1 .0056   0.
1 .0056   0.
1 .0056  90.
1 .0056 -45.
1 .0056  45. 1
$
2/0. 14. 0. 14./1  $(M-1,2A,5) RECTANGLE/ 14. x 14. PLATE/ WALL ID = 1
411 0 0 0 0 1  $    (N-1) - STANDARD MESH ELEM TYPE=411, REDUCED INTEGRATION
$
0 0 0 0      $      (P-1) - SPECIFY ALL BC S ON (P-2) CARDS
110 011      $      (P-2) - SIDE 1
110 101      $                   2
010 011      $                   3
100 101      $                   4 - RESTRAIN RIGID BODY MOTION IN V DIR
$
2             $   (G-1) - 2 LOAD SYSTEMS (B FOR TRIGGERING LOAD)
1 1           $   (Q-2)-  LOAD SYS A, NO. OF (Q-3) RECORDS=1
1. 2 1 1      $   (Q-3) - SIDE 1 LOAD MAG=-1., LINE LOAD ON ROW, U DIR, ROW 1
2 1           $   (Q-2) - LOAD SYS B, NO. OF (Q-3) RECS = 1
1.E-3 1 3 4 4 $   (Q-3) - LOAD=1.E-3 IN Z DIR AT ROW 3, COL 3
$ 0. -1 6     $    (Q-3) - ENFORCE 0 RW ROTATION FOR ALL NODES
$
1 2 0 0 0 1 $ (R-1) - OUTPUT CONTROL PRINT DISP, STRESS RESLNTS, POINT FORCES
```

change to displacement control for next run

Figure 5 Input for Nonlinear Analysis with Triggering Loads

```
KNCOMP4 - KNIGHT, W. TRIGGERING LOAD AND DISPLACEMENT CONTROLED
3 0 0 0 0 0 1  $    (B-1) - NONLINEAR , FULL PRINT OUT
1/1 0 1  $          (B-2,3)- NO. SHELL UNITS=1/ NO. MATLS=1 , NO. SHELL WALLS=1
1. 1. 20. 1. 1. 1. $ (C-1) - LOAD FACTOR = 1. , INCREM=1., MAX = 20.
0 750 3 10 $         (D-1) - NEW CASE, 750 CP SEC MAX, 3 LOAD CUTS, 10 REFACTRS
7 7$                 (F-1) - MESH = 7 X 7, I.E. 7 ROWS AND 7 COLUMNS
$
1/19.6+6 .0366 .93+6 0. 0. 1.89+6  $ (I-1,2) - MATERIAL ID/ MATERIAL PROPERTIES
$
1 1 8  $             (K-1) - WALL ID 1, GEN. LAYEREC, 8 LAYERS
1 .0056  45. 1    $ (K-2) - MATL ID=1, THICK=.0056, ANGLE=45., PRINT STRESS
1 .0056 -45.      $
1 .0056  90.      $                 REPEAT FOR EACH LAYER
1 .0056   0.
1 .0056   0.
1 .0056  90.
1 .0056 -45.
1 .0056  45. 1
$
2/0. 14. 0. 14./1  $(M-1,2A,5) RECTANGLE/ 14. X 14. PLATE/ WALL ID = 1
411 0 0 0 0 1  $    (N-1) - STANDARD MESH ELEM TYPE=411, REDUCED INTEGRATION
$
0 0 0 0      $       (P-1) - SPECIFY ALL BC S ON (P-2) CARDS
110 011      $       (P-2) - SIDE 1
110 101      $                      2
010 011      $                      3
100 101      $                      4 - RESTRAIN RIGID BODY MOTION IN V DIR
$
2              $   (Q-1) - 2 LOAD SYSTEMS (B FOR TRIGGERING LOAD)
1 1            $   (Q-2)-  LOAD SYS A, NO. OF (Q-3) RECORDS=1
5.E-5  -1  1  1 $(Q-3) - SPEC DISP=5.-5, IN X DIR ON ROW 1
2 1            $   (Q-2) - LOAD SYS B, NO. OF (Q-3) RECS = 1
1.E-3 1 3 4 4 $  (Q-3) - LOAD=1.E-3 IN Z DIR AT ROW 3, COL 3
$ 0. -1  6     $   (Q-3) - ENFORCE 0 RW ROTATION FOR ALL NODES
$
1 2 0 0 0 1 $ (R-1) - OUTPUT CONTROL PRINT DISP, STRESS RESLNTS, POINT FORCES
```

Figure 6   Input for Nonlinear Analysis with Displacement Control as the initial load. The reason for changing to a displacement controlled analysis was to attempt to load the plate through the buckling region. In general, this will be easier using displacement control since the stiffness matrix is constrained by the specified displacements; thus the stiffness matrix should not be as ill-conditioned as in a load-controlled situation. However, if the postbuckled structure softens drastically after buckling, then a solution through postbuckling may be quite difficult and require many restarts to accomplish. The present example is such a structure and will be discussed further in Section 2.1.5.

2.1.5 Discussion of Output and Results

The output for jobs KNCOMP0 through KNCOMP4 is presented in the appendix. Section 1.3 covered general interpretation of the output. Section 4.0 contains an annotated output for run KNCOMP4, which is a nonlinear analysis. Since most of the preprocessor (STAGS1) output and much of the solution (STAGS2) output for the linear statics (KNCOMP0) and linear buckling (KNCOMP1) are the same, the reader is referred to Section 4.0 for interpretation of this output. Additional comments on the buckling output (KNCOMP1) concerns the displacements. STAGSC-1 prints out several sets of displacements during a buckling analysis. The first set labeled "DISPLACEMENTS -- LINEAR SOLUTION --" are the displacements obtained using a linear statics solution to the problem. The next set labeled "DISPLACEMENTS MODE i" are the i'th modes' displacement pattern, and are not actual displacements. They are simply the displacement pattern and are usually normalized to a maximum value of 1.

Run KNCOMP3 is a nonlinear analysis with a small out-of-plane load (.001 lbs.) used to trigger the buckling mode. Load control was used to increment the load. The plot of maximum out-of-plane displacement versus end-shortening (Figure 7) shows that reasonable results are being obtained. Figure 8 indicates that the load in the skin (N_x) still appears to be linear prior to the

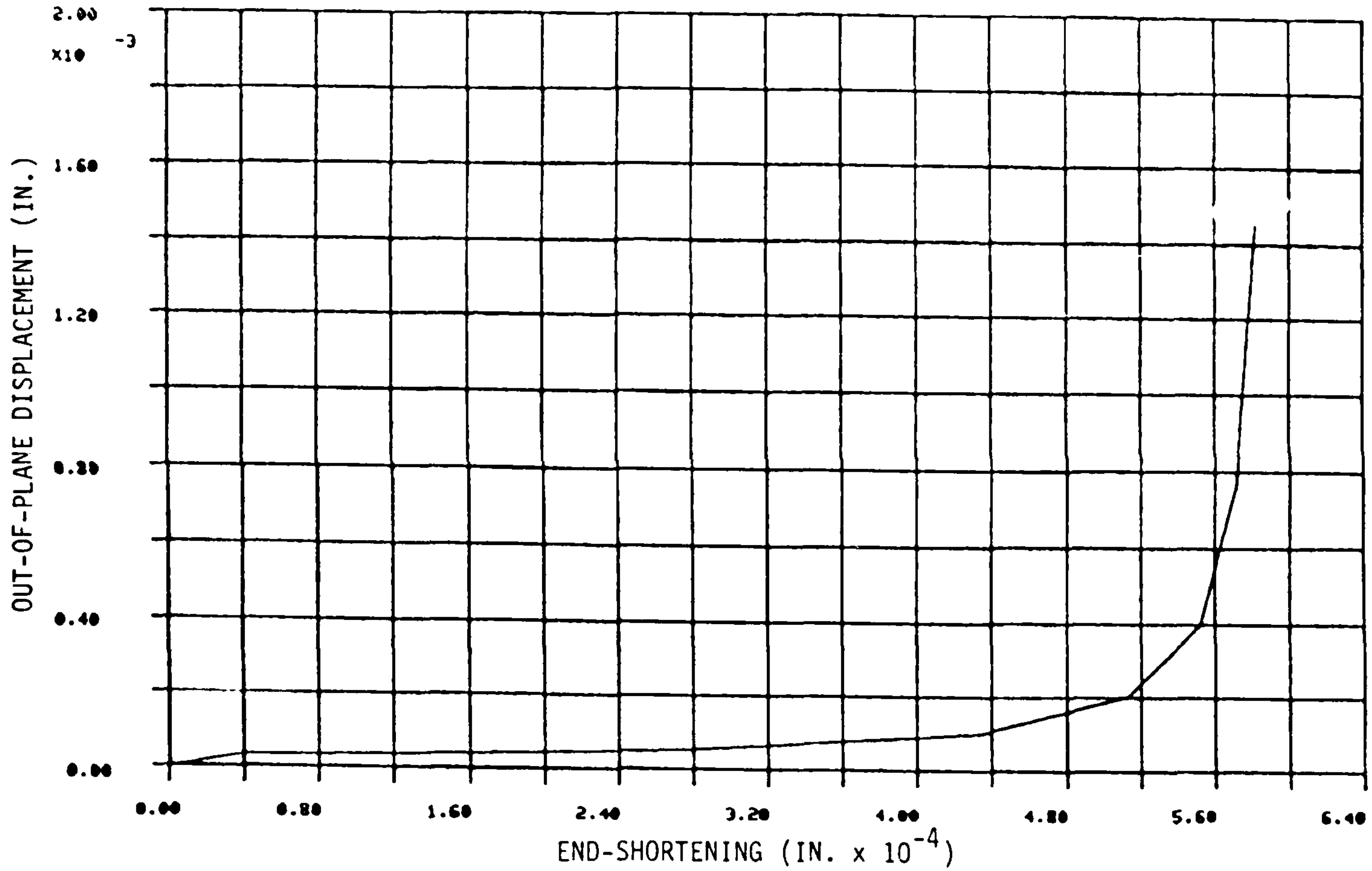


Figure 7 Out-of-Plane Displacement for Nonlinear Analysis of Flat Composite Plate

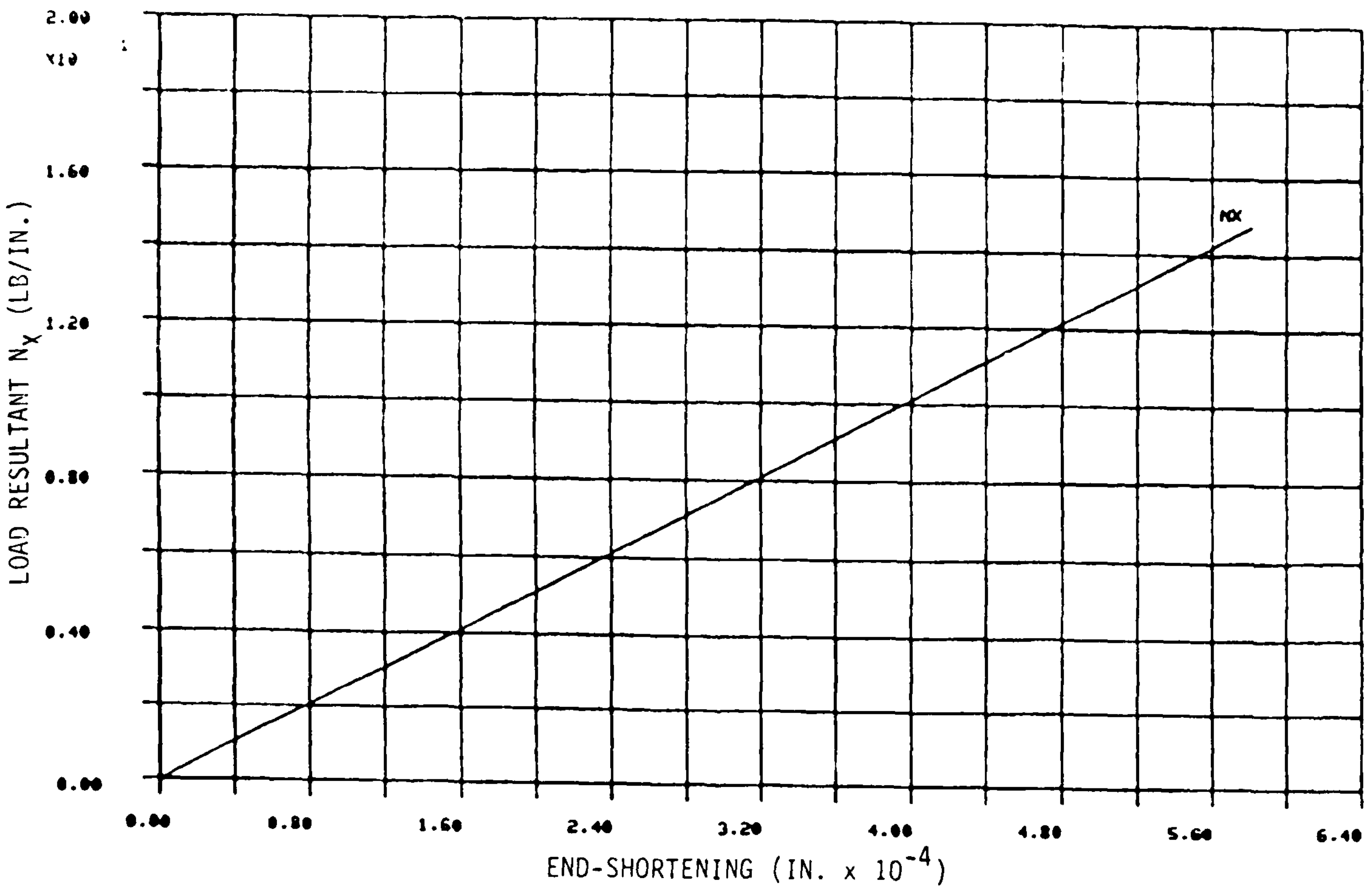


Figure 9 Load Resultant for Nonlinear Analysis of Flat Composite Plate

theoretical buckling load (15 lb/in). If the analysis were continued through buckling, one would expect N_x to begin to increase less rapidly with increased end-shortening. Note that at load step 9 (N_x = 14.75) the solution failed to converge. This is due to the fact that at the buckling load (N_x = 15), the stiffness matrix is singular for a load-controlled situation. Figures 8 and 9 were plotted using a separate plot routine not associated with the STAGSC-1 program.

Run KNCOMP4 was an attempt to use displacement control on the previous problem to allow solutions to be obtained through buckling. When a structure is loaded using displacement control, the stiffness matrix should not become singular for this problem, assuming the controlled displacements are chosen correctly. This is because when displacements are controlled, the stiffness matrix has the controlled degrees of freedom eliminated; thus, if the proper displacements are controlled (i.e., eliminated) the stiffness matrix will be rendered nonsingular. This will not always happen; for example, if a structure has several buckling modes that are not properly constrained, then the stiffness matrix will become singular due to the other buckling modes forming. In this example, the results are actually worse than those using load control. This is therefore another example of the often quoted unpredictability of nonlinear analysis. The displacement controlled approach will probably yield better results by sharpening (decreasing) the convergence criteria (DELX) and forcing the stiffness matrix to be updated more often. This approach will be discussed in Section 2.4 where it was used successfully. Note that the results obtained for KNCOMP3 and KNCOMP4 are not "wrong;" the solution, however, did not proceed as far as one might be interested in going. The interested reader is encouraged to run these problems and attempt to "extend" the solution obtained here.

2.2 FLAT COMPOSITE PLATE WITH STIFFENERS

This section describes a model of the flat plate shown in Figure 9. The plate has three stiffeners and is subjected to the shear load shown in Figure 9. The plate dimensions, layup, and stiffener properties are also shown in Figure 9. The boundary conditions will be described in Section 2.2.1. This sample demonstrates one option, the general stiffener section, for modeling stiffeners and also demonstrates the use of different initial and incremental boundary conditions on a structure. Note that the use of either the general stiffeners or of the subelement stiffener cards precludes certain stiffness distortions (see Appendix A for more on this).

2.2.1 Shear Buckling

The input file (CA2STIF) for the present problem is shown in Figure 10. Again, the input data cards have been defined in terms of STAGS nomenclature, and extensive comments are present. Differences between this input and the input for the plate of Section 2.1 will be described.

The input required to allow stiffeners (or rings) in a model affects the (B-2), (B-3), (F-2), "J", and "O" cards. The (B-2) and (B-3) cards state the number of shell units with discrete stiffeners and the number of different section property descriptions. For each shell unit, the (F-2) card states how many rings or stiffeners are present. The (J-1) and (J2-A) cards are then repeated for each section property description. Finally, the (O-2A) and (O-2B) cards are repeated the number of times defined on the (F-2) card; i.e., for each stiffener.

The present example demonstrates the use of different boundary conditions for the "pre-critical" stress state and the "incremental" solution. STAGS terminology "pre-critical" and "incremental" are now explained. In performing a linear buckling analysis two matrices are needed, the small displacement stiffness matrix K and the so called geometric stiffness matrix K_G.

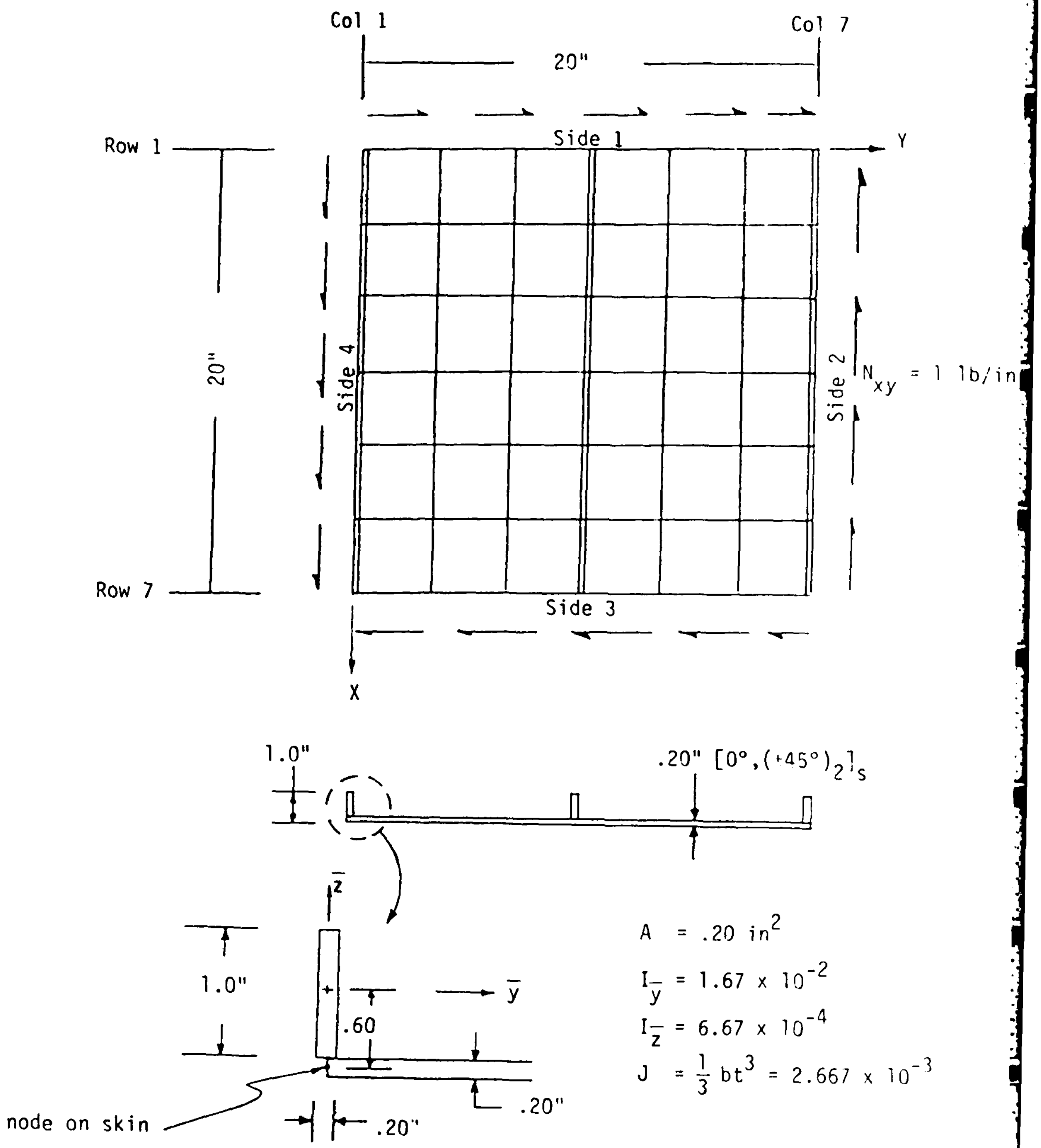


Figure 9 Model of Flat Plate with Stiffeners (Run [illegible])

```
CA2STIF  -  SHEAR BUCKLING OF COMPOSITE PLATE, 7 X 7 MESH W. 3 STIFFNERS
1 0 0 0 0 0 1  $       (B-1) - LINEAR BUCKLING, FULL PRINT OUT
1 0 1  $               (B-2) - NO. SHELL UNITS=1, NO. STIFFNER SETS =1
2 1 1 $                (B-3) - NO. MATLS=2, NO. BEAM SEC = 1, NO. SHELL WALLS = 1
1.   $                 (C-1) - LOAD FACTOR = 1.
1 0 500/2  $          (D-2,3)- 1 EIGENVALUE CLUSTER, 500 CP SEC MAX/ 2 EIGENVECS
7 7   $                (F-1) - MESH = 7 X 7, I.E. 7 ROWS AND 7 COLS
1 0 3 $                (F-2) - SHELL UNIT=1, NO. RINGS=0, NO. STRINGERS=3
$
1/26.+6 .06635 .44+6 0. 0. 6.9+6  $ (I-1,2) - MATERIAL ID/ MATERIAL PROPERTIES
2/15.+6 .3  $         (I-1,2)- FICTICOUS ISOTROPIC MATERIAL (ID=2) FOR STIFFNERS
$
1 1 2 0  2.67-3   $ (J-1) - CROSS SECTN ID=1, GENERL SECTN, MATID=2, J=2.67
.20 1.67-2 6.67-4 $ (J2-A)- STIFNER AREA=.20, IY=1.67, IZ=6.67
$
1 1 10  $              (K-1) - WALL ID 1, GEN. LAYERED, 10 LAYERS
1 .02 0. 1   $         (K-2) - MATL ID=1, THICK=.02, ANGLE=0., PRINT STRESS
1 .02 45.    $                 SAME AS ABOVE BUT ANGLE=45 AND DONT PRINT STRESSES
1 .02 -45.   $                 REPEAT
1 .02 45.
1 .02 -45.
1 .02 -45.
1 .02 45.
1 .02 -45.
```

Figure 10   Input for Linear Buckling (CA2STIF)

```
1 .02 45.
1 .02 0. 1   $      (K-2)
$
2/0. 20. 0. 20./1  $(M-1,2A,5) RECTANGLE/ 20. X 20. PLATE/ WALL ID = 1
411 0 0 0 0 1  $    (N-1) - STANDARD MESH ELEM TYPE=411, REDUCED INTEGRATION
$
1   0.   0.   .60   1 $ (O-2A)- CROSS SECTN ID=1, Z CG =.60 OFF PANEL, GEOM LINEAR
1   1    7            $ (O-2B)- STRINGER IS IN COL=1, ROWS 1-7
1   0.   0.   .60   1 $ (O-2A)- SAME
4   1    7            $ (O-2B)- STRINGER IS IN COL 4, ROWS 1-7
1   0.   0.   .60   1 $
7   1    7            $
$
0 0 0 0 1   $           (P-1) - PRESTRESS B.C. SPECIFIED ON (P-2), INCREM ON (P-3)
000 011/010 101/010 011/010 101  $ (P-2) - PRESTRESS BC ON SIDES 1 THRU 4
1 1 1 1   $             (P-3) - INCREMENTIAL BC IS SIMPLY SUPPORTED ON ALL 4 SIDES
$
1/ 1 4   $   (Q-1,2)- 1 LOAD SYSTEM/ LOAD SYS A, NO. OF (G-3) RECORDS
1.  2 2 1   $ (Q-3) - SIDE 1 LOAD MAG=1., LINE LOAD ON ROW, V DIR, ROW 1
-1. 3 1 0 7  $(Q-3) - SIDE 2        =-1., LL ON COL,        U DIR, ROW 0, COL 7
-1. 2 2 7  $  (Q-3) - SIDE 3
1.  3 1 0 1  $(Q-3) - SIDE 4
1 1 0 0 0 1  $(R-1) - OUTPUT CONTROL PRINT DISP, STRESS RESLNTS, POINT FORCES
```

Figure 10 (continued)

K_G is formed based upon a set of stresses and is a linear function of the stresses. The stresses used to form K_G are found from a linear statics solution using the "pre-critical" boundary conditions specified on the (P-1 and 2) cards. An eigenvalue analysis is then to be performed, specifically the eigenvalue problem,

$$(K + \lambda K_G)x = 0$$

is to be solved for a specified number of eigenvalues λ and eigenvectors (or modeshapes) x. The boundary conditions used to form the matrices in the above equation are the so called "incremental" boundary conditions and are specified on the (P-3) card. Appropriate rows and columns are added or deleted so that K_G and K are the same dimension. As can be seen, the buckling analysis is "inconsistent" in that the stresses are calculated for one boundary condition, while buckling is calculated for another boundary condition. However, this option may be used for modeling more complex situations. The beginning user is advised to experiment with and understand this option before utilizing it.

2.2.2 Output Discussion

The output for CA2STIF is contained in the appendix. The output obtained here is similar to the output discussed previously in Section 2.1.5, hence discussion will be brief. One point to note in the output is the presence of a negative eigenvalue. This indicates that the loads applied in the buckling analysis must actually be reversed in order to buckle the structure in the first mode (since only the first eigenvalue is negative for this output). That is, if the loads were reversed and the same buckling analysis were repeated, then the first eigenvalue would be positive and would have the same absolute value obtained in the appendix. The critical buckling load in the present case is given by:

$$N_{xy}^{cr} = -3826.3511 \times 1 \text{ lb/in} \approx -3826.35 \text{ lb/in}$$

since the applied load was 1 lb/in (see (Q-3) cards). That the applied load is 1 lb/in may be verified by examining the "EQUILIBRIUM FORCES" and noting that the accumulated force for row 1 in the Y direction is 20 lbs, which is 1 lb/in for a 20 in. wide panel.

2.3 CYLINDRICAL SHELL WITH STIFFENERS

Figure 11 presents a model of a curved panel with T stiffeners. The panel dimensions and loading are shown in Figure 11. The detail of the stiffener geometry is shown in Figure 12. Additionally, the auxiliary "bar" coordinate system which is used in describing the stiffener geometry and the relation to the shell "primed" coordinate system is shown. This example illustrates the use of a cylindrical surface definition, the subelement option for defining stiffener and ring cross sections, and the use of imposed displacements as loading conditions.

2.3.1 Compression Buckling of a Cylindrical Shell

Figure 13 presents the appropriate input data for performing a buckling analysis of the cylindrical shell of Figure 11. The shell definition is affected using cards (M-1), (M-2A), and (M-5). The stiffeners are defined as in Section 2.2, except (J-3B) cards are used to define the cross section instead of the (J-2A) cards used in Section 2.2. The (J-3B) cards are repeated for each subelement and specify the locations of the rectangular subelements in terms of the "bar" axis of Figure 12. Points for stress recovery are defined on the second (J-3B) card. The "bar" axis orientation relative to the "primed" axis (defined at each node) is specified on (O-2A) cards along with the cross section identification numbers.

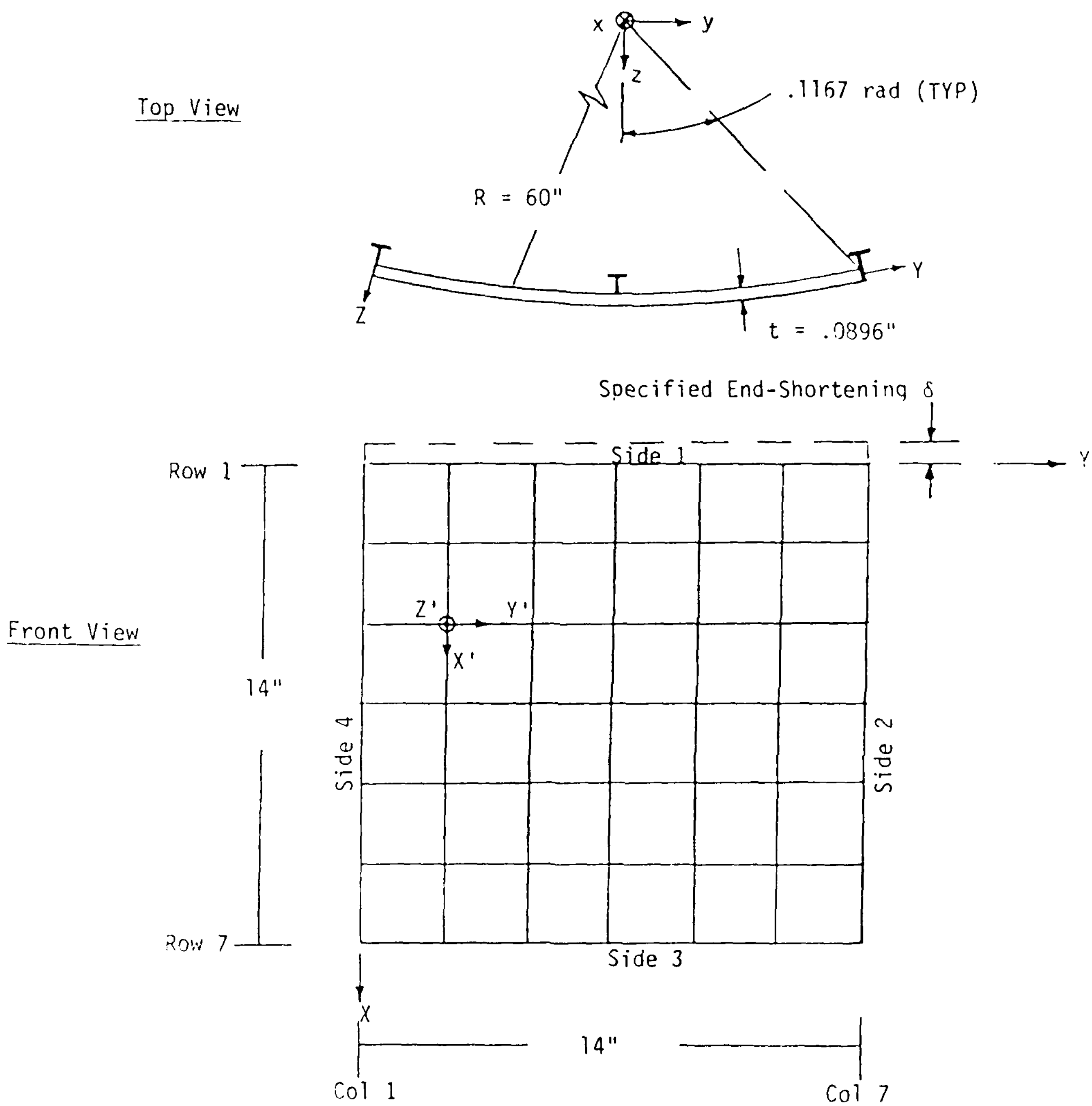
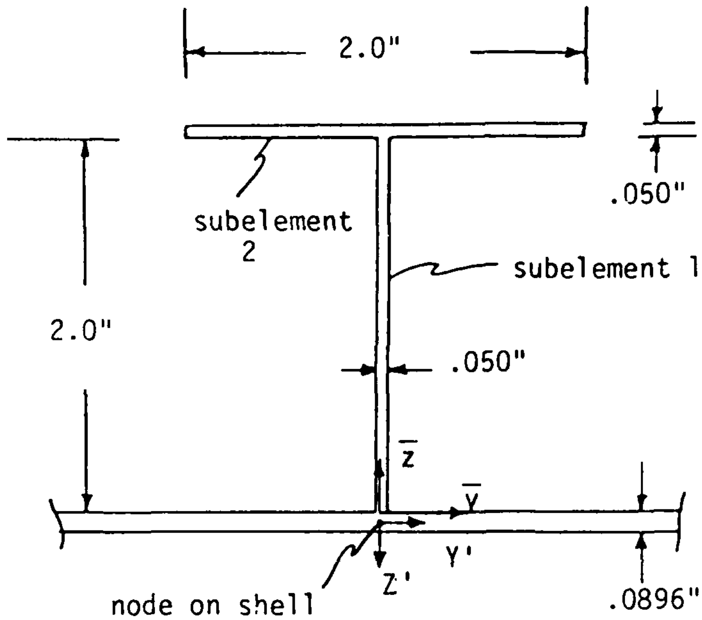


Figure 11 Model of Curved Cylindrical Panel with T-Stiffeners



Shear Center Location:

$$SCZ \cong 2.0" \quad , \quad SCY = 0$$

$$J \cong \sum \frac{bt^3}{3} = 2(2)\left(\frac{.050)^3}{3}\right) = 1.667 \times 10^{-4}$$

Figure 12 Detailed Geometry of Stiffener

```
CYL1 - COMPRESS. BUCK. OF STIFFENED CYL. SHELL, 7x7 MESH
1 0 0 0 0 0 1  $       (B-1) - LINEAR BUCKLING, FULL PRINT OUT
1 0 1  $               (B-2) - NO. SHELL UNITS=1, NO. STIFFNER SETS =1
2 1 1 $                (B-3) - NO. MATLS=2, NO. BEAM SEC = 1, NO. SHELL WALLS = 1
1.   $                 (C-1) - LOAD FACTOR = 1.
1 0 500/2  $          (D-2,3)- 1 EIGENVALUE CLUSTER, 500 CP SEC MAX/ 2 EIGENVECS
7 7   $                (F-1) - MESH = 7 X 7, I.E. 7 ROWS AND 7 COLS
1 0 3 $                (F-2) - SHELL UNIT=1, NO. RINGS=0, NC. STRINGERS=3
$
1/26.+6 .06635 .44+6 0. 0. 6.9+6  $ (I-1,2) - MATL ID=1/ MATERIAL PROPERTIES
2/15.+6 .3  $         (I-1,2)- FICTICOUS ISOTROPIC MATERIAL (ID=2) FOR STIFFNERS
$
1 3 2 2  1.67-4 0. 2. 2 $ (J-1) - CROSS SECTN ID=1, REC SUBELEMS, MATID=2,
$                                 NO. SUBELEMS=2, J=1.67-4,
$                                 SHEAR CEN AT (Y=0., Z=2.), 2 STRESS PTS
-.025 .025 .0448 2.0      $(J-3B)- LOC OF SUBELM 1,SEE ASSOCIATD FIGURE IN TEXT
-1.0  1.0  2.0   2.05 1 1 $(J-3B)- LOC OF SUBELM 2, 2 STRESS PTS OUTPUT
$
1 1 16  $              (K-1) - WALL ID 1, GEN. LAYERED, 16 LAYERS
1 .0056  45. 1 $       (K-2) - MATL ID=1, THICK=.0056, ANGLE=45, PRINT STRESS
1 .0056 -45.   $               SAME AS ABOVE BUT ANGLE=-45 AND DONT PRINT STRESS
1 .0056  90.   $               REPEAT
1 .0056   0.
1 .0056   0.
1 .0056  90.
1 .0056 -45.
1 .0056  45.
$              PLANE OF SYMMETRY
1 .0056  45.
1 .0056 -45.
```

Figure 13   Input for CYL1 Problem

```
1 .0056  90.
1 .0056   0.
1 .0056   0.
1 .0056  90.
1 .0056 -45.
1 .0056  45. 1 $     (K-2)   FOR LAST (16TH) LAYER, PRINT STRESS
$
5/0. 14. -6.68 6.68 60./1 $(M-1,2A,5)- CYL/H=14., TOTAL ANGLE=2*6.68 DEG,
$                                          RADIUS=60.,/ WALL ID = 1
411 0 0 0 0 1  $     (N-1) - STANDARD MESH ELEM TYPE=411, REDUCED INTEGRATION
$
1 180.  0.  -.0448    $ (O-2A)- CROSS SECTN ID=1, ANG OF BAR AXES=180. DEG,
$                               BAR AXIS (Y,Z)=(0.,-.0448)FROM NODE, GEOM LIN
1  1   7              $ (O-2B)- STRINGER IS IN COL=1, ROWS 1-7
1 180.  0.  -.0448    $ (O-2A)- SAME
4  1   7              $ (O-2B)- STRINGER IS IN COL 4, ROWS 1-7
1 180.  0.  -.0448    $ (O-2A)
7  1   7              $ (O-2B)
$
0 0 0 0       $        (P-1) - SPECIFY ALL BC S ON (P-2) CARDS
110 011       $        (P-2) - SIDE 1
110 101       $                     2
010 011       $                     3
100 101       $                     4 - RESTRAIN RIGID BODY MOTION IN V DIR
$
1/ 1 1            $  (Q-1,2)- 1 LOAD SYSTEM/ LOAD SYS A, NO. OF (Q-3) RECORDS=1
1.E-6  -1  1  1  $   (Q-3) - ENFORCED DISP=1.E-6, U DIR, ROW 1
$
1 1 1 1 0 1 $ (R-1) - OUTPUT CONTROL PRINT DISP, STRESS , POINT FORCES
```

Figure 13 (continued)

The compression load is applied as an imposed displacement of .001 inches on side 1. Additional output has been requested on the (R-1) card and will be discussed in Section 2.3.2.

2.3.2 Output Descriptions for Compression Buckling of Cylindrical Panel

The output for CYL1 is contained in the appendix. Note, in the STAGS1 output, the SURFACE COORDINATES vs. GLOBAL CARTESIAN COORDINATES (Page 6 of output). This is a good check to ensure that the shell option and input geometry is correct. See Section 1.1.2 of this report and Section 2 of [1] for further discussion of surface coordinates. In order to validate this model, an additional run with a small modulus input for the stiffeners was made. The results of this analysis (essentially no stiffeners) was then compared to the exact solution for a curved panel [4].

2.4 ONE-BAY MODEL OF STIFFENED SKIN

The final sample problem is a one-bay model of a stiffened skin panel. The stiffened panel to be analyzed is shown in Figure 14. It was found from tests of the panel that the stiffeners were so stiff that buckling of the skin was the only concern. The buckle pattern was established and it was found that only one-half of a bay needed to be modeled as depicted in Figure 14.

This sample problem illustrates the following techniques and capabilities of STAGSC-1:

- Use of symmetry in modeling
- Use of linear buckling to establish preliminary buckling load
- Use of imperfections in triggering desired buckling patterns in nonlinear analysis
- The restart capabilities

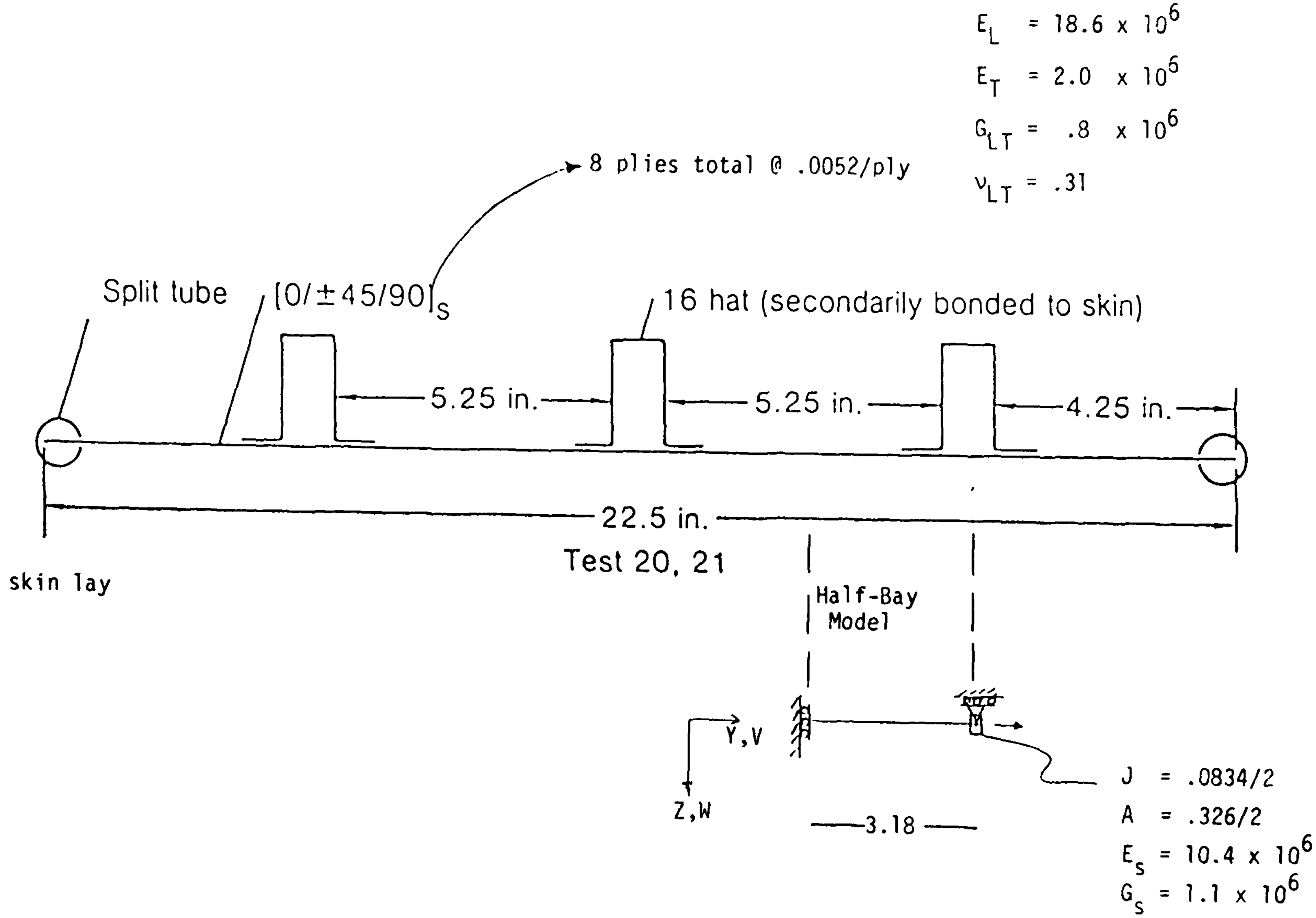


Figure 14 Cross-Section of Hat-Stiffened Panels

Since this report is aimed at the beginner in finite element analysis some comments on the use of symmetry are in order. Symmetry, when it can be established, enables the modeler to model only a portion of a structure. For example, in the linear static analysis of a simple plate, loaded by uniform endloads along the length of the plate, only a quarter of the plate needs to be modeled. Appropriate symmetry conditions for the center lines of the actual plate are then used as boundary conditions for the quarter model. This allows not only a much more economical solution to the problem, but a solution which is actually more accurate than if the entire plate were modeled. If the entire plate were modeled, and the symmetry conditions were not obtained in the displacement output, the differences could only be attributable to numerical round-off or the inaccuracy of the finite elements used. The ability to detect symmetry conditions will not only allow the engineer to perform more cost effective analysis, but also allows the detection of certain modeling errors. Additionally, detection of symmetry conditions indicates good engineering intuition and understanding of the physical problem. However, in buckling analysis, the buckled mode must be known before symmetry can be used. Erroneous answers will result if boundary conditions are imposed which do not allow the correct buckle pattern for the entire plate. In the following example, half of a stiffened skin bay was modeled. This was allowed since the buckled pattern was known prior to the analysis.

2.4.1 Linear Compression Buckling

The mathematical model is shown in Figure 15. Boundary conditions, panel geometry and ply layups are also presented. The main purpose of this analysis was to perform a nonlinear analysis of the post-buckled skin-stiffener combination. In order to get a feel for the buckling load, a linear buckling analysis was first performed. The input (GDCPAN1) is presented in Figure 16. The input is well documented with comments and is

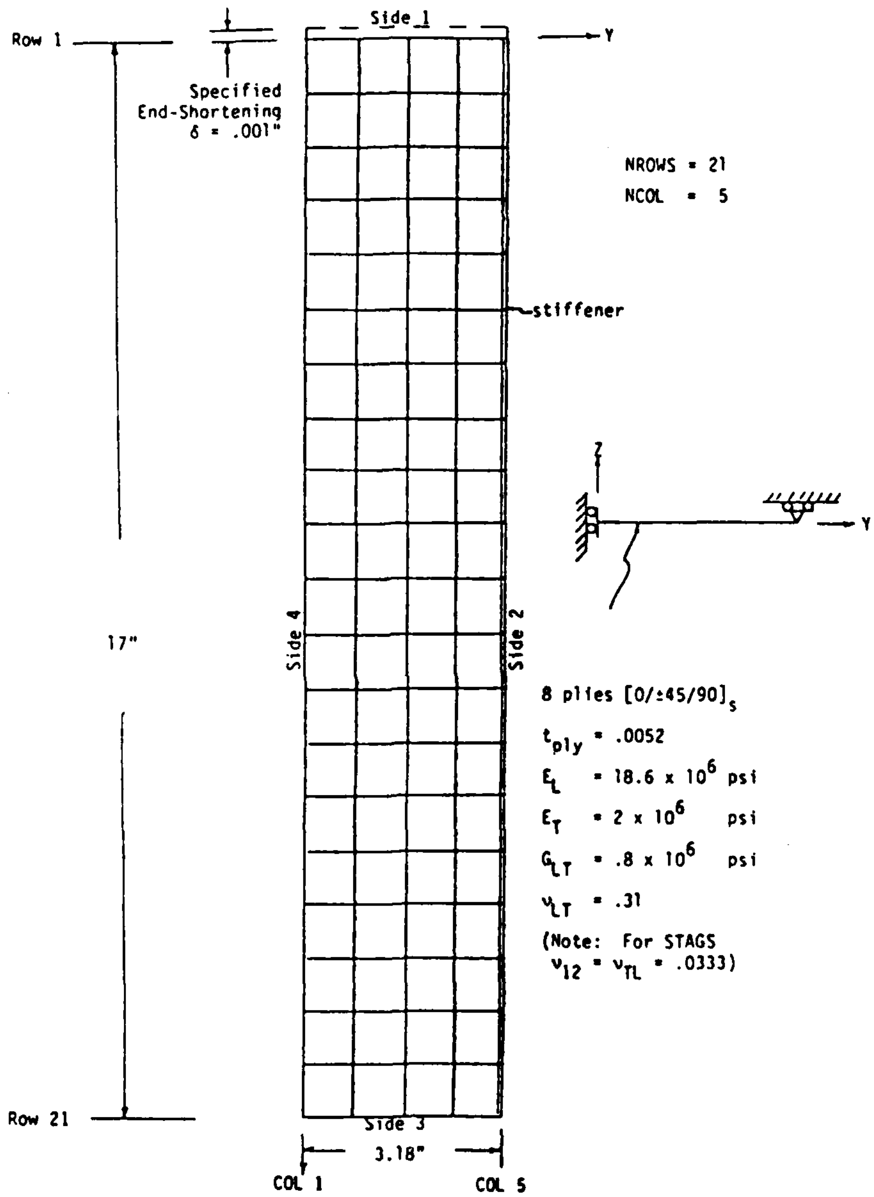


Figure 15 Symmetric One-Bay Model of Stiffened Skin

```
GDCPAN1 - COMP BUCKLING OF GDC PANEL, 1/2 BAY MODEL, CLAMPED AT TOP & BOTTOM
1 0 0 0 0 0 1  $     (B-1) - LINEAR BUCKLING, FULL PRINT CUT
1 0 1  $             (B-2) - NO. SHELL UNITS=1, NO. STIFFNER SETS =1
2 1 1 $              (B-3) - NO. MATLS=2, NO. BEAM SEC = 1, NO. SHELL WALLS = 1
1.   $               (C-1) - LOAD FACTOR = 1.
1 0 750/2  $        (D-2,3)- 1 EIGENVALUE CLUSTER, 750 CP SEC MAX/ 2 EIGENVECS
21 5  $              (F-1) - MESH = 21 ROWS AND 5 COLS
1 0 1 $              (F-2) - SHELL UNIT=1, NO. RINGS=0, NO. STRINGERS=1
$
1/18.6+6 .0333 .8C+6 0. 0. 2.+6 $(I-1,2)-MAT ID/ E1=18.6, U12=.03, G=.8, E2=2.
2/10.4+6  0.  1.1+6  $             (I-1,2)- STIFFNER MATERIAL, E=10.4, G=1.1
$
1 1 2 0  .0417   $  (J-1) - CROSS SECTN ID=1, GENERL SECTN, MATID=2, J=.0417
.163             $  (J2-A)- STIFNER AREA=.163
$
1 1 8  $            (K-1) - WALL ID 1, GEN. LAYERED, 8 LAYERS
1 .0052   0. 1 $    (K-2) - MATL ID=1, THICK=.0052, ANGLE=0., PRINT STRESS
1 .0052  45.   $            SAME AS ABOVE BUT ANGLE=45 AND DONT PRINT STRESSES
1 .0052 -45.   $            REPEAT
1 .0052  90.
1 .0052  90.
1 .0052 -45.
1 .0052  45.
1 .0052   0. 1
$
2/0. 17. 0. 3.18/1  $(M-1,2A,5) RECTANGLE/ 17. X 3.18 PLATE/ WALL ID = 1
411 0 0 0 0 1  $     (N-1) - STANDARD MESH ELEM TYPE=411, REDUCED INTEGRATION
$
1  0.  0.  .0  1 $ (O-2A)- CROSS SECTN ID=1, Z CG =.0 OFF PANEL, GEOM LINEAR
5  1   21        $ (O-2B)- STRINGER IS IN COL=5, ROWS 1-21
$
0 0 0 0      $       (P-1) - ALL BCS ON (P-2) CARD
110 000      $       (P-2) - SIDE 1
110 101      $                    2
010 000      $                    3
101 011      $                    4
1/1 1           $ (Q-1,2) - 1 LOAD SYS/ LOAD SYS A, NO. OF (Q-3) RECS
.001  -1  1  1  $ (Q-3)   - SPECIFIED END-SHORTNING OF .001 IN U DIR ROW 1
1 1 0 0 0 1  $(R-1) - OUTPUT CONTROL PRINT DISP, STRESS RESLNTS, POINT FORCES
```

Figure 16   Input for Linear Buckling Analysis of Half-Bay Model very similar to that previously discussed in Sections 2.1.2 and 2.3.1. The output for the buckling analysis is labeled GDCPAN1 and will be discussed in Section 2.4.5.

2.4.2 Nonlinear Analysis with Initial Imperfections

As discussed in [1], it is often necessary to use initial imperfections in a nonlinear analysis to "trigger" the buckling mode. This was found necessary for the present panel. The first nonlinear analysis simply loaded up to several times the buckling load with no indication of nonlinearity. Thus, an approximation to the buckling pattern shown in Figure 17, from GDCPAN1 was used as an initial imperfection pattern. Alternately, the buckling mode calculated in Section 2.4.1 could have been saved on TAPE22 using the (B-2) card and then used here via the (B-2) and (B-5) card combinations. The input for the analysis is shown in Figure 18 and will be referred to as GDCPAN7. Besides adding in the appropriate cards for changing from a buckling analysis to a nonlinear analysis (discussed in Section 2.1.3), the following changes are made:

- Card (B-1) specifies to save all displacement data
- Card (C-1) specifies to save both the element (unfactored) and the factored stiffness matrices
- Card (M-6) defines the initial imperfections

The JCL to save the appropriate files for this analysis is shown in Figure 19. The displacement data is saved on GDCPAN7.SOD and is always output on FORTRAN unit 22. Similarly, the element (unfactored) stiffness matrix and the factored stiffness matrix are output on FORTRAN units 23 and 24, respectively. The output for this analysis will be discussed in Section 2.4.5.

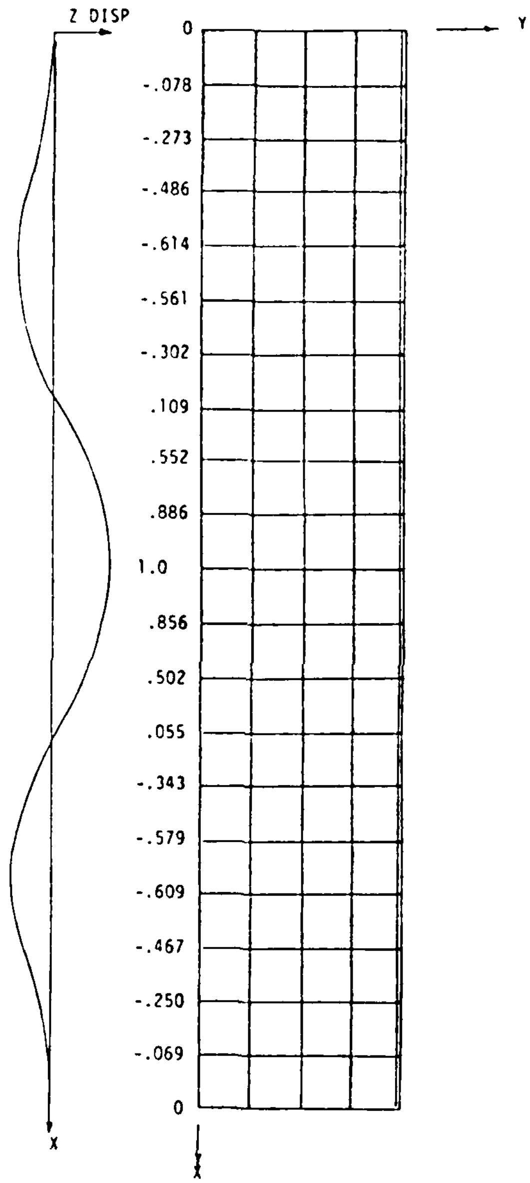


Figure 17 Buckling Pattern Along Edge of Half-Bay Model

```
GCCPAN7 - POST BUCKLING OF GDC PANEL, 1/2 BAY MODEL, W. INIT IMPERFECTION
3 0 1 0 0 0 1  $     (B-1) - NONLINEAR STATIC, FULL PRINT OUT, NO RESTART
1 0 1  $             (B-2) - NO. SHELL UNITS=1, NO. STIFFNER SETS =1
2 1 1 $              (B-3) - NO. MATLS=2, NO. BEAM SEC = 1, NO. SHELL WALLS = 1
.1  .1  1.5  1. 1. 2.  0  0  -1  -1  $(C-1)
$                     (C-1)-INIT LOAD FACTOR=.1, INCREM=.1, MAX=1.5,RESTART
0  3000 5  -1  $     (D-1) - NEW CASE, 750 SEC, 5 LOAD CUTS, UPDATE K EVERY STEP
21 5  $              (F-1) - MESH = 21 ROWS AND 5 COLS
1 0 1 $              (F-2) - SHELL UNIT=1, NO. RINGS=0, NO. STRINGERS=1
$
1/18.6+6 .0333 .80+6 0. 0. 2.+6 $(I-1,2)-MAT ID/ E1=18.6, U12=.03, G=.8, E2=2.
2/10.4+6  0.  1.1+6  $            (I-1,2)- STIFFNER MATERIAL, E=10.4, G=1.1
$
1 1 2 0  .0417    $  (J-1) - CROSS SECTN ID=1, GENERL SECTN, MATID=2, J=.0417
.163              $  (J2-A)- STIFNER AREA=.163
$
1 1 8  $            (K-1) - WALL ID 1, GEN. LAYERED, 8 LAYERS
1 .0052   0. 1 $    (K-2) - MATL ID=1, THICK=.0052, ANGLE=0., PRINT STRESS
1 .0052  45.   $            SAME AS ABOVE BUT ANGLE=45 AND DONT PRINT STRESSES
1 .0052 -45.   $            REPEAT
1 .0052  90.
1 .0052  90.
```

Figure 18   Input for Nonlinear Analysis with Initial Imperfections

```
1 .0052 -45.
1 .0052  45.
1 .0052   0. 1
$
2/0. 17. 0. 3.18/1 1 $(M-1,2A,5) RECTANGLE/ 17. X 3.18 PLATE/ WALL ID = 1
8.5  0.  5.67  6.36  1.E-3  $ (M-6) INITIAL IMPERFECTION DEFINITION
411 0 0 0 0 1  $    (N-1) - STANDARD MESH ELEM TYPE=411, REDUCED INTEGRATION
$
1  0.  0.  .0  0 $ (O-2A)- CROSS SECTN ID=1, Z CG =.0 OFF PANEL, GEOM NONLINEAR
5  1   21         $ (O-2B)- STRINGER IS IN COL=5, ROWS 1-21
$
0 0 0 0      $       (P-1) - ALL BCS ON (P-2) CARD
110 000      $       (P-2) - SIDE 1  CLAMPED
110 101      $                    2  SIMPLE SUPPORT
010 000      $                    3  CLAMPED + FIX VERTICAL (X) MOTION
101 011      $                    4  SYMETRY CONDITION + FIX LATERIAL (Y) MOTION
1                $ (Q-1) - 1 LOAD SYS
1 1              $ (Q-2) -  LOAD SYS A, NO. OF (Q-3) RECS
.0045  -1  1  1 $ (Q-3)    - SPECIFIED END-SHORTNING OF .0045 IN U DIR ROW 1
1 2 0 0 0 1  $(R-1) - OUTPUT CONTROL PRINT DISP, STRESS RESLNTS, POINT FORCES
```

Figure 18 (continued)

```
$
$!  PROCEDURE TO EXECUTE STAGS1 AND STAGS2
$
$ SET DEF (.STAGS)
$ SET VERIFY
$ ASSIGN GDCPAN7.INP FOR005
$ ASSIGN GDCPAN7.OU1 FOR006
$ RUN (STAGSC1)STAGS1.EXE
$ ASSIGN GDCPAN7.OU2 FOR006
$ ASSIGN GDCPAN7.SOD FOR022
$ ASSIGN GDCPAN7.KEL FOR023
$ ASSIGN GDCPAN7.KFA FOR024
$ RUN (STAGSC1)STAGS2.EXE
```

Figure 19 JCL for Saving Data from GDCPAN7 for Restart

2.4.3 Restart of Nonlinear Solution with Stiffness Matrices

The input for restarting the GDCPAN7 run is presented in Figure 20 and is labeled GDCPAN8. The only difference between this input and that of GDCPAN7 is that the (C-1) card is modified to start the load increment at one of the previous solutions (.928125 in this case), and the stiffness matrices are read but not saved. It is noted that in order to restart, the stiffness matrices need not be saved; only the displacement data is necessary. Also, the (C-1) card specifies that a load step .05 be used compared to the previous value of .10. The (D-1) card specifies to start at the twelfth step of the previous analysis (load factor = .928125). The JCL to run GDCPAN8 is presented in Figure 21. The displacement file saved as GDCPAN7.SOD is equivalenced to FORTRAN unit 20 for restart. The displacements to be saved from GDCPAN8 are saved on GDCPAN8.SOD and are equivalenced to FORTRAN unit 22. The stiffness matrices are equivalenced to the same units that were used to save them (23 and 24). Note that STAGS does not have an option to read both factored and unfactored stiffness matrices and write out the latest factored and unfactored matrices in one run.

2.4.4 Restart of Nonlinear Solution without Stiffness Matrices

The input presented in Figure 22 is now used to restart run GDCPAN8. The (C-1) record indicates that the initial load factor to be used is 1.278125 and that stiffness matrices are not to be read. Thus, only the displacements will be used in the restart procedure. Also, the (C-1) card specifies that the load step be .025 and that loading proceed until a factor of 1.75 is obtained. Card (D-1) specifies that loading will start with the eighteenth load step from the previous solution and the convergence factor (DELX) has been reduced to 1×10^{-6}. The reduction of load steps and allowable convergence error are typical techniques used to improve convergence in nonlinear analysis. Also, the updating of the stiffness matrix every step ((D-1) card) increases the rate of convergence. These various procedures of nonlinear analysis are discussed in Section 6 of [1] and Chapter 6 of [2].

```
GDCPAN8 - POST BUCKLING OF GDC PANEL, 1/2 BAY MODEL, W. INIT IMPERFECTION
3 0 1 0 0 0 1  $    (B-1) - NONLINEAR STATIC, FULL PRINT CUT, NO RESTART
1 0 1  $            (B-2) - NO. SHELL UNITS=1, NO. STIFFNER SETS =1
2 1 1 $             (B-3) - NO. MATLS=2, NO. BEAM SEC = 1, NO. SHELL WALLS = 1
.928125  .05  1.5  1. 1. 2.  0  0  1  1  $(C-1)
$                    (C-1)-INIT LOAD FACTOR=.1, INCREM=.1, MAX=1.5,RESTART
12  1000 5  -1  $   (D-1) - NEW CASE, 750 SEC, 5 LOAD CUTS, UPDATE K EVERY STEP
21 5  $             (F-1) - MESH = 21 ROWS AND 5 COLS
1 0 1 $             (F-2) - SHELL UNIT=1, NO. RINGS=0, NO. STRINGERS=1
$
1/18.6+6 .0333 .80+6 0. 0. 2.+6 $(I-1,2)-MAT ID/ E1=18.6, U12=.03, G=.8, E2=2.
2/10.4+6  0.  1.1+6  $          (I-1,2)- STIFFNER MATERIAL, E=10.4, G=1.1
$
1 1 2 0  .0417    $  (J-1) - CROSS SECTN ID=1, GENERL SECTN, MATID=2, J=.0417
.163              $  (J2-A)- STIFNER AREA=.163
$
1 1 8  $            (K-1) - WALL ID 1, GEN. LAYERED, 8 LAYERS
1 .0052   0. 1 $    (K-2) - MATL ID=1, THICK=.0052, ANGLE=0., PRINT STRESS
1 .0052  45.   $            SAME AS ABOVE BUT ANGLE=45 AND DONT PRINT STRESSES
1 .0052 -45.   $            REPEAT
1 .0052  90.
1 .0052  90.
```

Figure 20   Input for Restart of GDCPAN7

```
1 .0052 -45.
1 .0052  45.
1 .0052   0. 1
$
2/0. 17. 0. 3.18/1 1 $(M-1,2A,5) RECTANGLE/ 17. X 3.18 PLATE/ WALL ID = 1
8.5  0.  5.67  6.36  1.E-3  $ (M-6) INITIAL IMPERFECTION DEFINITION
411 0 0 0 0 1  $    (N-1) - STANDARD MESH ELEM TYPE=411, REDUCED INTEGRATION
$
1  0.  0.  .0  0 $ (O-2A)- CROSS SECTN ID=1, Z CG =.0 OFF PANEL, GEOM NONLINEAR
5  1  21         $ (O-2B)- STRINGER IS IN COL=5, ROWS 1-21
$
0 0 0 0     $       (P-1) - ALL BCS ON (P-2) CARD
110 000     $       (P-2) - SIDE 1  CLAMPED
110 101     $                    2  SIMPLE SUPPORT
010 000     $                    3  CLAMPED + FIX VERTICAL (X) MOTION
101 011     $                    4  SYMETRY CONDITION + FIX LATERIAL (Y) MOTION
1                $ (G-1) - 1 LOAD SYS
1 1              $ (G-2) -  LOAD SYS A, NO. OF (Q-3) RECS
.0045  -1  1  1 $ (Q-3)   - SPECIFIED END-SHORTNING OF .0045 IN U DIR ROW 1
1 2 0 0 0 1  $(R-1) - OUTPUT CONTROL PRINT DISP, STRESS RESLNTS, POINT FORCES
```

Figure 20 (continued)

```
$
$! PROCEDURE TO EXECUTE STAGS1 AND STAGS2
$
$ SET DEF (.STAGS)
$ SET VERIFY
$ ASSIGN GDCPAN8.INP FOR005
$ ASSIGN GDCPAN8.OU1 FOR006
$ RUN (STAGSC1)STAGS1.EXE
$ ASSIGN GDCPAN8.OU2 FOR006
$ ASSIGN GDCPAN7.SOD FOR020
$ ASSIGN GDCPAN8.SOD FOR022
$ ASSIGN GDCPAN7.KEL FOR023
$ ASSIGN GDCPAN7.KFA FOR024
$ RUN (STAGSC1)STAGS2.EXE
```

Figure 21 JCL to Run GDCPAN8

```
GDCPAN9 - POST BUCKLING OF GDC PANEL, 1/2 BAY MODEL, W. INIT IMPERFECTION
3 0 1 0 0 0 1  $    (B-1) - NONLINEAR STATIC, FULL PRINT CUT, NO RESTART
1 0 1  $            (B-2) - NO. SHELL UNITS=1, NO. STIFFNER SETS =1
2 1 1 $             (B-3) - NO. MATLS=2, NO. BEAM SEC = 1, NO. SHELL WALLS = 1
.1278125+1  .025  1.75  1. 1. 2.  0  0     $(C-1)
$                    (C-1)-INIT LOAD FACTOR=.12, INCREM=.C25, MAX=1.75,RESTART
18  2000 5  -1  0  1.E-6 $(D-1) RESTRT FROM LOAD STEP 18, 2000 SEC, 5 LOAD CUTS
$                               UPDATE K EVERY STEP, EXTRAP SOL, DISP ERR=5E-5
21 5  $             (F-1) - MESH = 21 ROWS AND 5 COLS
1 0 1 $             (F-2) - SHELL UNIT=1, NO. RINGS=0, NO. STRINGERS=1
$
1/18.6+6 .0333 .8C+6 0. 0. 2.+6 $(I-1,2)-MAT ID/ E1=18.6, U12=.03, G=.8, E2=2.
2/10.4+6  0.  1.1+6  $            (I-1,2)- STIFFNER MATERIAL, E=10.4, G=1.1
$
1 1 2 0  .0417    $  (J-1) - CROSS SECTN ID=1, GENERL SECTN, MATID=2, J=.0417
.163              $  (J2-A)- STIFNER AREA=.163
$
1 1 8  $           (K-1) - WALL ID 1, GEN. LAYERED, 8 LAYERS
1 .0052   0. 1 $   (K-2) - MATL ID=1, THICK=.0052, ANGLE=0., PRINT STRESS
1 .0052  45.   $           SAME AS ABOVE BUT ANGLE=45 AND DONT PRINT STRESSES
1 .0052 -45.   $           REPEAT
1 .0052  90.
```

Figure 22   Input to Restart GDCPAN8

```
1 .0052  90.
1 .0052 -45.
1 .0052  45.
1 .0052   0. 1
$
2/0. 17. 0. 3.18/1 1 $(M-1,2A,5) RECTANGLE/ 17. X 3.18 PLATE/ WALL ID = 1
8.5  0.  5.67  6.36  1.E-3  $ (M-6) INITIAL IMPERFECTION DEFINITION
411 0 0 0 0 1  $    (N-1) - STANDARD MESH ELEM TYPE=411, REDUCED INTEGRATION
$
1  0.  0.  .0  0 $ (O-2A)- CROSS SECTN ID=1, Z CG =.0 OFF PANEL, GEOM NONLINEAR
5  1   21         $ (O-2B)- STRINGER IS IN COL=5, ROWS 1-21
$
0 0 0 0      $       (P-1) - ALL BCS ON (P-2) CARD
110 000      $       (P-2) - SIDE 1  CLAMPED
110 101      $                    2  SIMPLE SUPPORT
010 000      $                    3  CLAMPED + FIX VERTICAL (X) MOTION
101 011      $                    4  SYMETRY CONDITION + FIX LATERIAL (Y) MOTION
1                $ (Q-1) - 1 LOAD SYS
1 1              $ (Q-2) -  LOAD SYS A, NO. OF (Q-3) RECS
.0045  -1  1  1 $ (Q-3)   - SPECIFIED END-SHORTNING OF .0045 IN U DIR ROW 1
1 2 0 0 0 1  $(R-1) - OUTPUT CONTROL PRINT DISP, STRESS RESLNTS, POINT FORCES
```

Figure 22 (continued)

Figure 23 presents the JCL to run GDCPAN9. As can be seen, the displacements saved from GDCPAN8 (GDCPAN8.SOD) are equivalenced to FORTRAN unit 20 while the current displacements are being saved on FORTRAN unit 22 in case another restart is required. The output for this run will be discussed in Section 2.4.5.

2.4.5 Output Discussion of Half-Bay Stiffened Skin

Runs GDCPAN1, 8, and 9 are contained in the appendix. GDCPAN1 is a standard linear buckling analysis which predicts a total buckling load of: $P = \lambda P' = 4.584 \times 158.15 \approx 725$. The value of $P' = 158.15$ lbs is obtained from the output under "EQUILIBRIUM FORCES -- LINEAR SOLUTION" and is the accumulated force on row 1 for an enforced displacement of .001 in. GDCPAN7 is a displacement controlled run which uses initial imperfections obtained from GDCPAN1 to trigger the buckling pattern. GDCPAN7 was run until a load step of .928 of the theoretical buckling load. At this point, insufficient computer time was left to continue the analysis. The stiffness matrices and displacements vectors were saved to restart the problem.

GDCPAN8 is a restart of GDCPAN7. The load step was halved due to anticipated problems with convergence. The run continued loading from the previous .928 to a load factor of 1.28. At this point, insufficient time was again the reason for termination of the run.

GDCPAN9 restarted GDCPAN8 only using the displacements from the previous run. The load was successfully applied to a load factor of 1.75 times the initial buckling load. Normal termination then occurred. Both the load step and displacement error (DELX) were made smaller in anticipation of convergence problems.

The maximum out-of-plane displacement vs. end-shortening is presented in Figure 24. As can be seen, nonlinearities occur at an end-shortening of about .003 inches which is less than the critical end-shortening (.005 in.) predicted using the buckling analysis. Figure 25 shows the total load and the load in the stiffener as a function of end-shortening. As can be seen, a

```
$
$!  PROCEDURE TO EXECUTE STAGS1 AND STAGS2
$
$ SET DEF (.STAGS)
$ SET VERIFY
$ ASSIGN GDCPAN9.INP FOR005
$ ASSIGN GDCPAN9.OU1 FOR006
$ RUN (STAGSC1)STAGS1.EXE
$ ASSIGN GDCPAN9.OU2 FOR006
$ ASSIGN GDCPAN8.SOD FOR020
$ ASSIGN GDCPAN9.SOD FOR022
$ RUN (STAGSC1)STAGS2.EXE
```

Figure 23   JCL for GDCPAN9

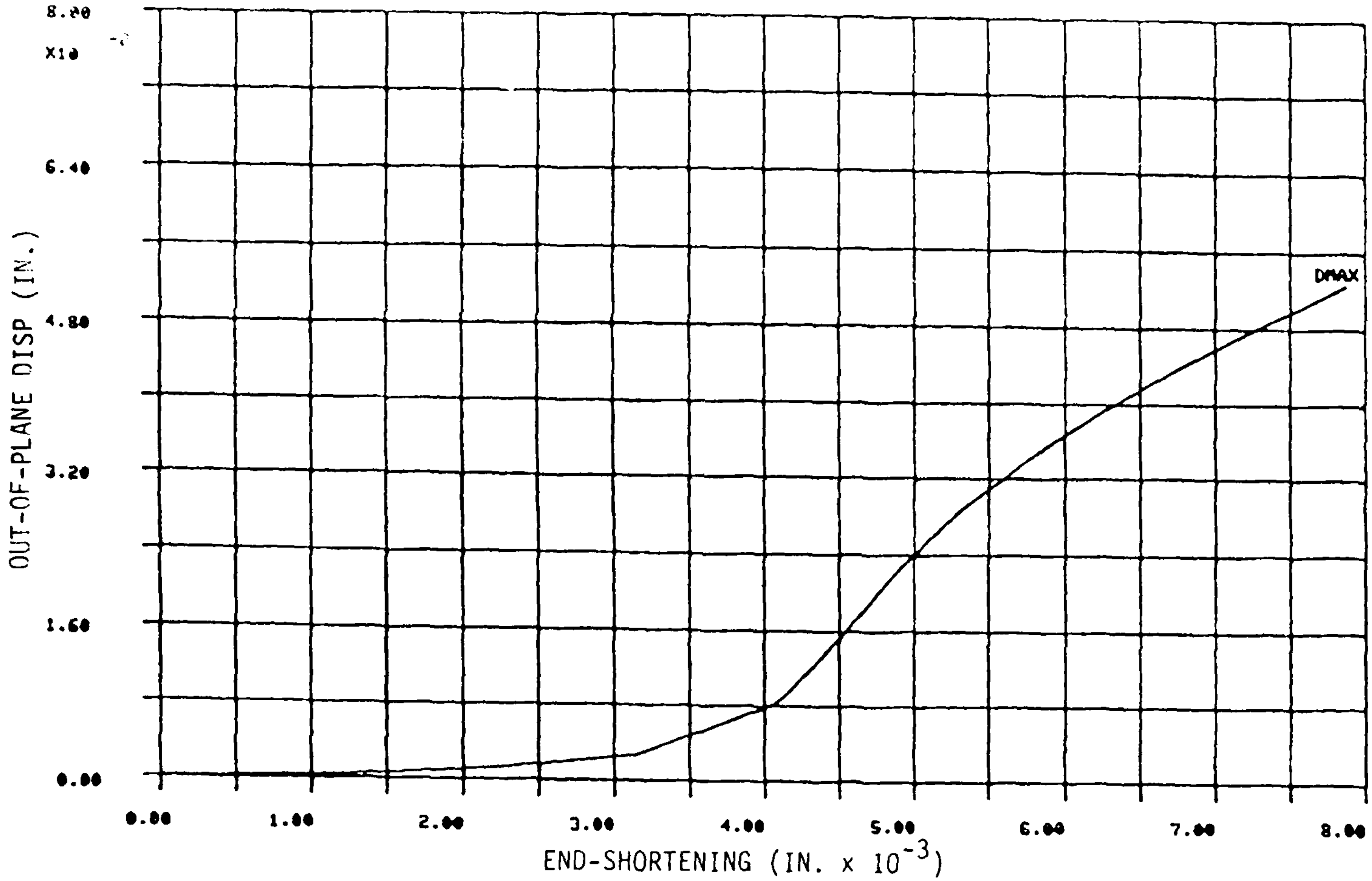


Figure 24 Maximum Out-of-Plane Displacement for GDCPAN7

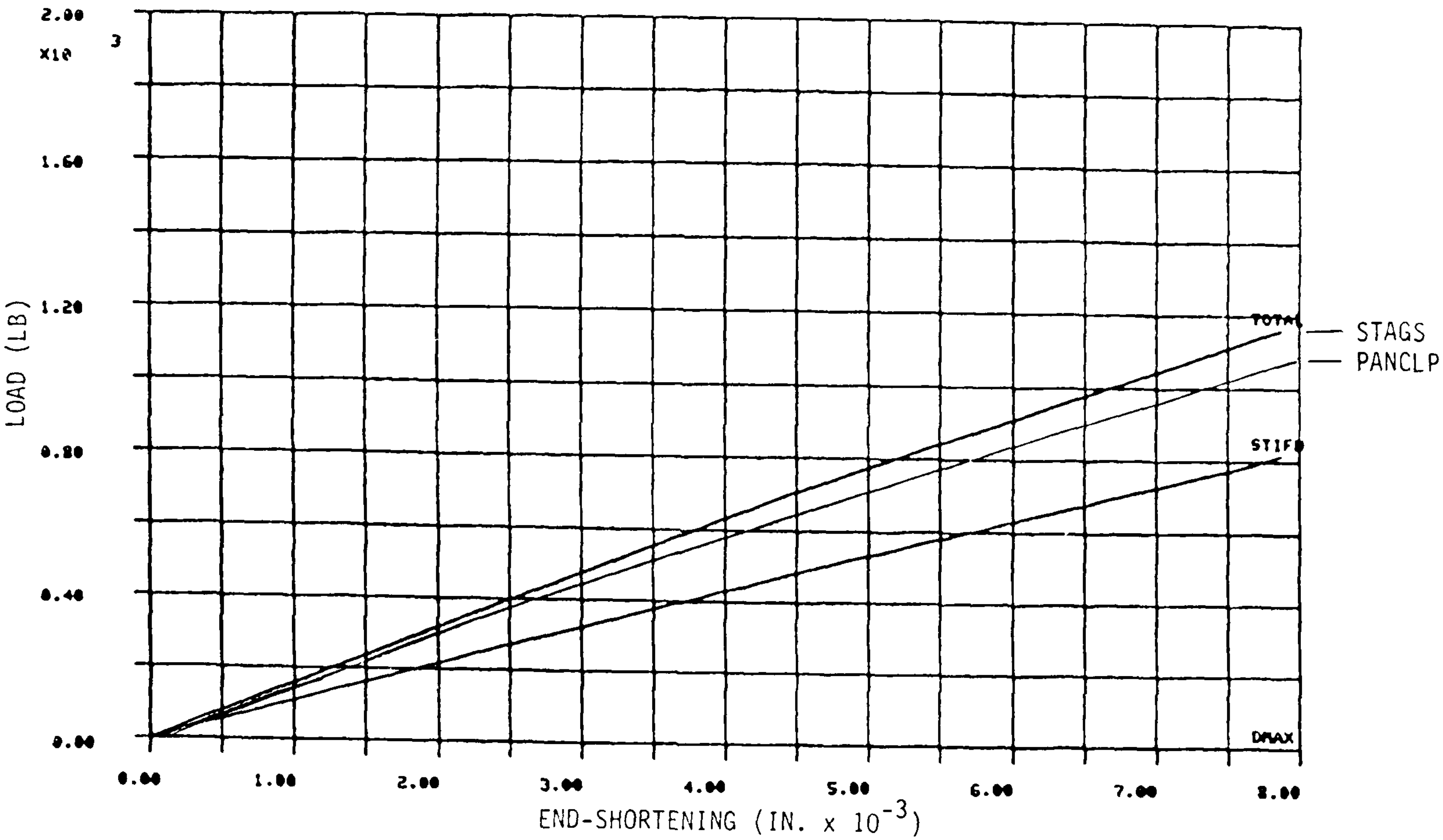


Figure 25 Total Load and Stiffener Load for GEOPAN7

slight decrease in linearity and load occurs near the end-shortening of .005 in. which is as anticipated. The stiffener load remains essentially linear due to its high stiffness and constraints imposed along its length.

For comparison, another load vs. end-shortening curve for this panel is presented in Figure 25. This curve was predicted using the PANCLP [5] program. Comparing these two curves indicates reasonable agreement between STAGSC-1 and PANCLP. It is noted that due to the specialized nature of the PANCLP program, its associated computer cost was about one-tenth that of the STAGSC-1 program.

3.0 ADVANCED PROBLEMS

Appendices A through D contain four examples of STAGSC-1 advanced modeling capability. These examples were contributed by Norman F. Knight Jr. of NASA Langley Research Center whose helpful comments and example problems are here acknowledged.

The sample problems are considered fairly self-explanatory and are not elaborated upon herein. Appendix A is a study of modeling the distortions of stiffeners using STAGSC-1. Appendix B is an example of how to model a multi-branched structure. Appendix C is an example of modeling a complex "pear" shaped shell. Appendix D presents an example of utilizing the "User Written Subroutine" capability of STAGSC-1. These examples should aid users of STAGSC-1 in utilizing these more advanced capabilities.

4.0 ANNOTATED OUTPUT FOR NONLINEAR ANALYSIS (KNCOMP4)

Appendix E contains portions of the output from an analysis previously described (KNCOMP4, Section 2.1.4). Since it is often difficult to explain something without seeing it, Appendix E presents the output with abbreviated explanations printed on the actual output. Refer back to Section 2.1.4 for details concerning the model's geometry, loads, etc.

REFERENCES

1. Almroth, B. O., Brogan, F. A., and Stanley, G. M., "Structural Analysis of General Shells," Vol. II, User Instructions for STAGSC-1, LMSC-D633873, Lockheed Palo Alto Research Laboratory, Jan. 1983.

2. Thomas, K., and Sobel, L. H., "Evaluation of the STAGSC-1 Shell Analysis Computer Program," WARD-10881, Westinghouse Electric Corp., Prepared for Office of Naval Research, Contract No. N00014-79-C-0825, 1981.

3. Zienkiewicz, O. C., The Finite Element Method, 3rd Ed., McGraw-Hill, 1977.

4. Roark, R. J., and Young, W. C., Formulas for Stress and Strain, 5th Ed., p. 554, McGraw-Hill, 1975.

5. Arnold, R. R., and Parekh, J. C., "PANCLP - Version 25.0," Anamet Report No. 84.001B, June 30, 1984.

6. Almroth, B. O., and Brogan, F. A., "Computational Efficiency of Shell Elements," Nonlinear Finite Element Analysis of Plates and Shells, AMD-Vol. 40, pp. 147-166, 1981.

APPENDIX A

REQUIRED MODELING DETAIL
FOR STIFFENED PANELS

REQUIRED MODELING DETAIL IDENTIFIED FOR STIFFENED PANELS WITH BUCKLED SKINS

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Structural Mechanics Branch, SDD
Extension 4585
November 13, 1981

(RTOP 505-33-33)

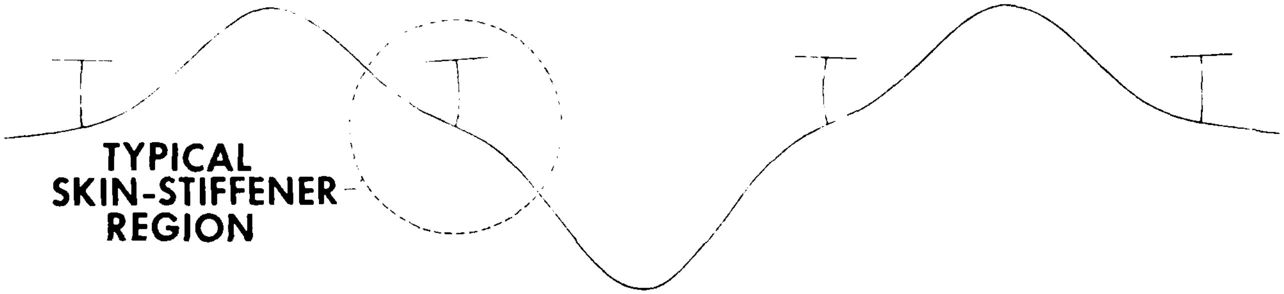
The design of stiffened panels with buckled skins is of considerable interest to the aerospace industry because of the significant weight saving potential of buckled skin designs when compared with buckling resistant designs. In buckled skin designs, local skin buckling is allowed which results in additional load being transferred to the stiffeners. Because postbuckling deformation shapes can be highly complex, the analytical modeling detail that is required is not known in advance and must be established for each stiffened panel design. One modeling criterion that appears to have merit is based on the requirement that the model used to predict the postbuckling response of a stiffened panel must first predict accurately the initial buckling response. With this criterion in mind, a study was made to identify the modeling detail required by a nonlinear finite element code called STAGS that can be used to study the postbuckling response of stiffened panels. The buckling load and corresponding mode shape obtained with PASCO, an efficient and accurate code for calculating only initial buckling results, were used as the standards for comparison in this study. The panel selected for the study is a flat graphite-epoxy panel with a 16-ply skin and four I-stiffeners. The buckled cross section of the panel as determined by PASCO is shown in the upper figure. These buckling results indicate that the stiffener webs deform and that local bending occurs near the skin-stiffener interface.

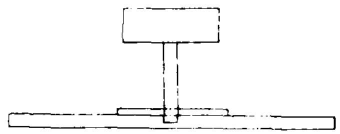
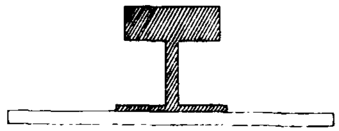
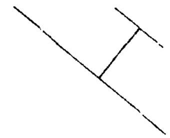
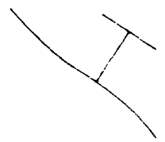
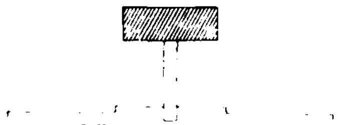
Several STAGS models with varying levels of modeling sophistication in the skin-stiffener region are shown in the table along with the buckled cross sections. In the analysis of stiffened panels, the traditional approach has been to model the stiffeners as discrete beams. A discrete beam model accounts for extensional, bending and torsional stiffnesses and any eccentricities of the stiffener by lumping these properties at the skin-stiffener attachment points. As such, the discrete beam model, STAGS-1, neglects not only the cross sectional deformations of the stiffener but also any local bending near the skin-stiffener interface. The buckling load for the STAGS-1 model is 10.6% smaller than the PASCO results because the STAGS-1 model has a larger effective stiffener spacing. The larger effective stiffener spacing is a result of lumping the properties of the attachment flanges at discrete points. In order to model the local bending near the skin-stiffener interface, a plate model, STAGS-2, of the attachment flanges is used and gives a buckling load which is 17.9% higher than the PASCO buckling load. The buckling load is higher because the discrete beam representation of the stiffener webs used in the STAGS-2 model does not allow for the rolling of the stiffeners. The next refinement, STAGS-3, treated the stiffener webs, in addition to the attachment flanges, as plate elements which then allows both local bending and cross sectional deformations of the web to be predicted accurately.

It appears that the level of modeling detail required for accurate analyses of stiffened composite panels which are designed to operate with buckled skins is greater than the level of modeling detail that previously was used throughout the discipline for buckling resistant panels.

REQUIRED MODELING DETAIL IDENTIFIED FOR STIFFENED PANELS WITH BUCKLED SKINS

BUCKLED CROSS SECTION



ANALYTICAL MODEL	MODEL OF TYPICAL SKIN-STIFFENER REGION	BUCKLED CROSS SECTION OF TYPICAL SKIN-STIFFENER REGION	DEVIATION FROM PASCO BUCKLING RESULTS
PASCO			---
STAGS -1			-10.6%
STAGS -2			17.9%
STAGS -3			1.4%

---PLATE ELEMENT ---BEAM ELEMENT

APPENDIX B

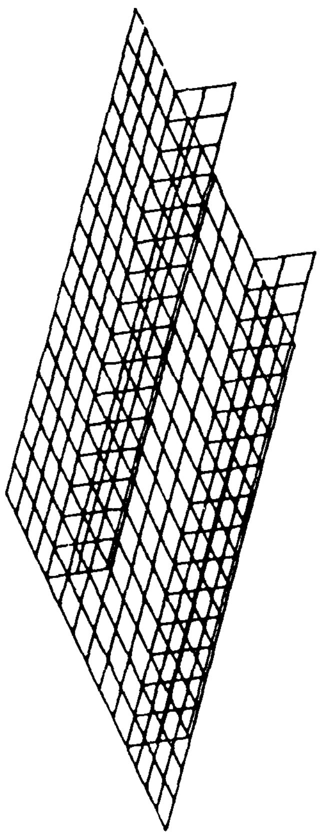
MODELING OF MULTI-BRANCHED STRUCTURES

5 BRANCH STIFFENED PANEL MODEL

PLOT NO. 1, UNIT 0

MODEL GEOMETRY

MODEL SCALE = .2500E+00, ORIENT. = -15.00, -45.00, -60.00



```
5 BRANCH STIFFENED PANEL MODEL
 3  1  1  0  0  0  1  0  $B-1
5  0  0  4  10  0  1$  B-2
   1   0   2  $ B-3
 0.084E-2   $B-5
 1.88906  0.01  3.0   $C-1
26  5000  8  8  0  1.0E-4  $D-1
  17,5  17,3  17,7  17,3  17,5
C
C  DEFINE CONNECTIONS BETWEEN SHELL UNITS
C
  1   2    3   4   $ G-1
  1  2    2  4  $G-1
   3  2    4  4  $G-1
  3   2    5   4   $ G-1
C
C DEFINE PARTIAL COMPATIBILITY CONSTRAINTS
C FOR UNIFORM END SHORTENING
C
 3  1   3  1    1  1   0  1   $G-2
 3  1   3  1    2  1   0  1   $G-2
 3  1   3  1    3  1   0  1   $G-2
 3  1   3  1    4  1   0  1   $G-2
 3  1   3  1    5  1   0  1   $G-2
 3 17   3  1    1 17   0  1   $G-2
 3 17   3  1    2 17   0  1   $G-2
 3 17   3  1    3 17   0  1   $G-2
 3 17   3  1    4 17   0  1   $G-2
 3 17   3  1    5 17   0  1   $G-2
C
C MATERIAL AND WALL DATA
C
  1     $ I-1
 1.32E7  .3  4.54E6  .101  0.0  9.8E6  0.0  $I-2
  1  1  1   $ K-1
  1  .084   $ K-2
  2  1  1   $ K-1
  1  .058   $ K-2
C
C UNIT  1
  2   3  $M-1
  0. 15. 0. 2.5 $ M-2A
0.  0.  0.        $ M-4
0.  2.5  0.       $ M-4
15.  2.5  0.      $ M-4
  1               $ M-5
411 $
1  6  1  4  $  P-1
0  0  0  0  $  Q-1
```

```
  1   5              $ R-1
C UNIT 2
  2   3    $ M-1
  0. 15. 0. 1.352     $  M-2A
0.  2.5  0.           $ M-4
  0. 2.5     1.352    $  M-4
 15. 2.5     1.352    $  M-4
  2                   $  M-5
411 $
1 6 1 6 $ P-1
0  0  0  0  $  Q-1
  1   5               $  R-1
C UNIT 3
  2   3               $  M-1
  0.  15. 0. 5.0      $  M-2A
0.0  2.5  0.0         $ M-4
  0.  7.5 0.0         $  M-4
 15.  7.5 0.0         $  M-4
  1                   $  M-5
411 $
1  6  1  6  $  P-1
1  0  0  0  $  Q-1
  1  3  $Q-2
 8000.0   1  1  1  3  0  $Q-3
-8000.0   1  1  17  3  0  $Q-3
 0.0  -1  1  9  3  0  $Q-3  ELIMINATE U RIGID BODY MOTION
  1   5               $  R-1
C UNIT 4
  2   3               $  M-1
  0. 15. 0. 1.352     $  M-2A
0.0  7.5  0.0         $ M-4
  0. 7.5    1.352     $  M-4
 15. 7.5    1.352     $  M-4
2                     $ M-5
411 $
1 6 1 6 $ P-1
0  0  0  0  $  Q-1
  1  5                $  R-1
C UNIT 5
  2   3               $  M-1
  0. 15.0 0. 2.5      $  M-2A
0.  7.5  0.0  $  M-4
0.  10.0  0.0  $  M-4
15.  10.  0.0  $  M-4
1                     $  M-5
411 $
1  4  1  6  $  P-1
0  0  0  0  $  Q-1
 1 5                  $  R-1
```

```
    5 BRANCH STIFFENED PANEL MODEL
21 1   3.0   0  $   PL-2
    0   0   $PL-3
    0.25   -15.0    -45.0    -60.0   1.0   $PL-4
    1   0 -1   0   1   5   0   3  $PL-3
    0.25   -15.0    -45.0    -60.0   2.50   $PL-4
1   0 -1   0   1 10   0   3 0   0   -1 $   PL-3
1   0 -1   0   1 15   0   3 0   0   -1 $   PL-3
1   0 -1   0   1 20   0   3 0   0   -1 $   PL-3
1   0 -1   0   1 25   0   3 0   0   -1 $   PL-3
1   0 -1   0   1 30   0   3 0   0   -1 $   PL-3
1   0 -1   0   1 35   0   3 0   0   -1 $   PL-3
1   0 -1   0   1 40   0   3 0   0   -1 $   PL-3
1   0 -1   0   1 45   0   3 0   0   -1 $   PL-3
1   0 -1   0   1 50   0   3 0   0   -1 $   PL-3
    2   3 -1   0   1   5   0   3  $PL-3
    0.25   .0   0.0    0.0   100.0    10$PL-4
2   3 -1   0   1 10   0   3 0   0   -1 $   PL-3
2   3 -1   0   1 15   0   3 0   0   -1 $   PL-3
2   3 -1   0   1 20   0   3 0   0   -1 $   PL-3
2   3 -1   0   1 25   0   3 0   0   -1 $   PL-3
2   3 -1   0   1 30   0   3 0   0   -1 $   PL-3
2   3 -1   0   1 35   0   3 0   0   -1 $   PL-3
2   3 -1   0   1 40   0   3 0   0   -1 $   PL-3
2   3 -1   0   1 45   0   3 0   0   -1 $   PL-3
2   3 -1   0   1 50   0   3 0   0   -1 $   PL-3
```

APPENDIX C

PEAR-SHAPED SHELL MODEL

Material Properties:

$E = 10^7$ psi

$\nu = 0.3$

$\gamma = 0.1$ lb/in^3

Geometric Parameters:

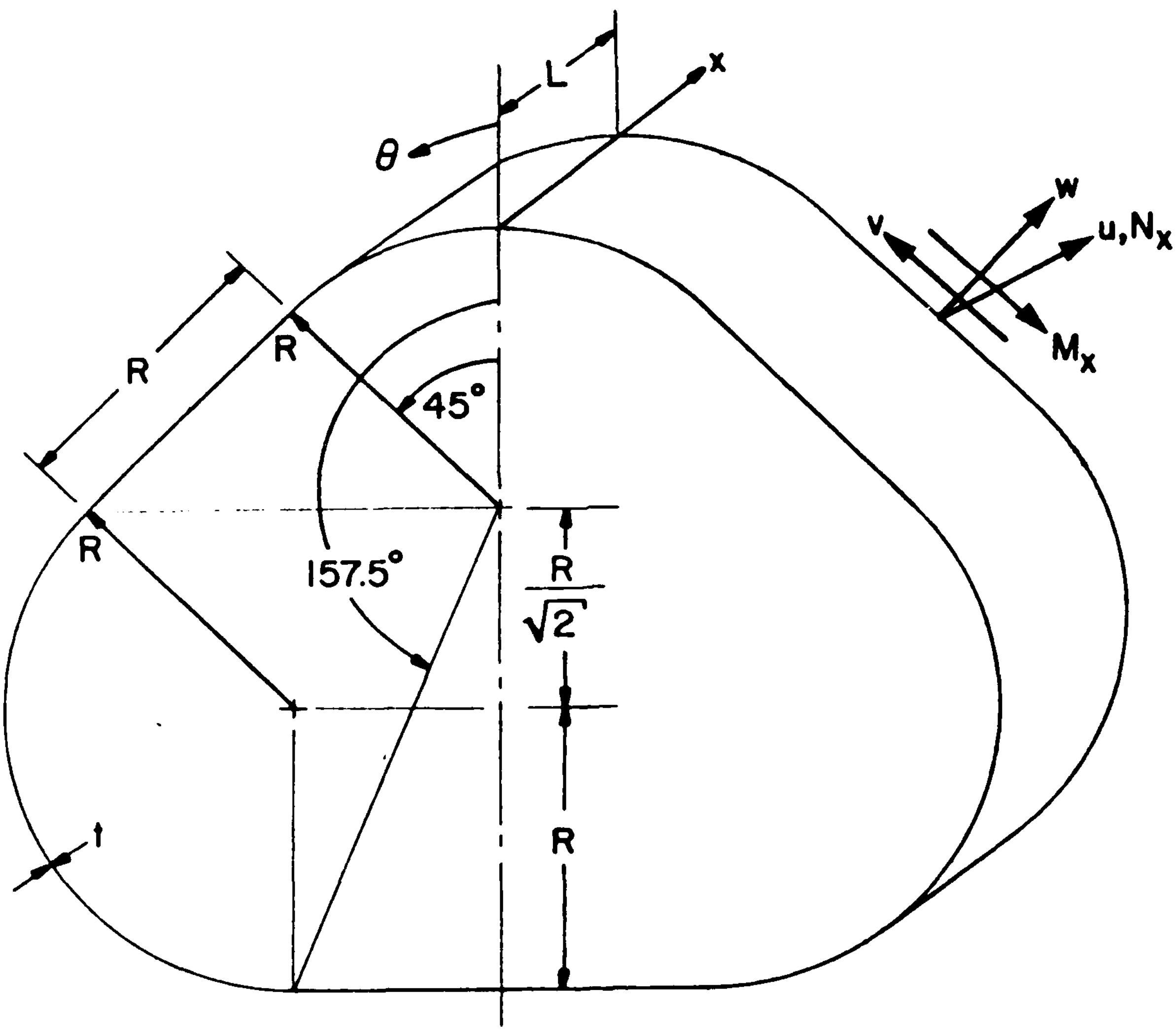
R = 1.0 inch

L = 0.8 inches

t = 0.01 inches

Boundary Conditions:

$v = w = M_x = 0$



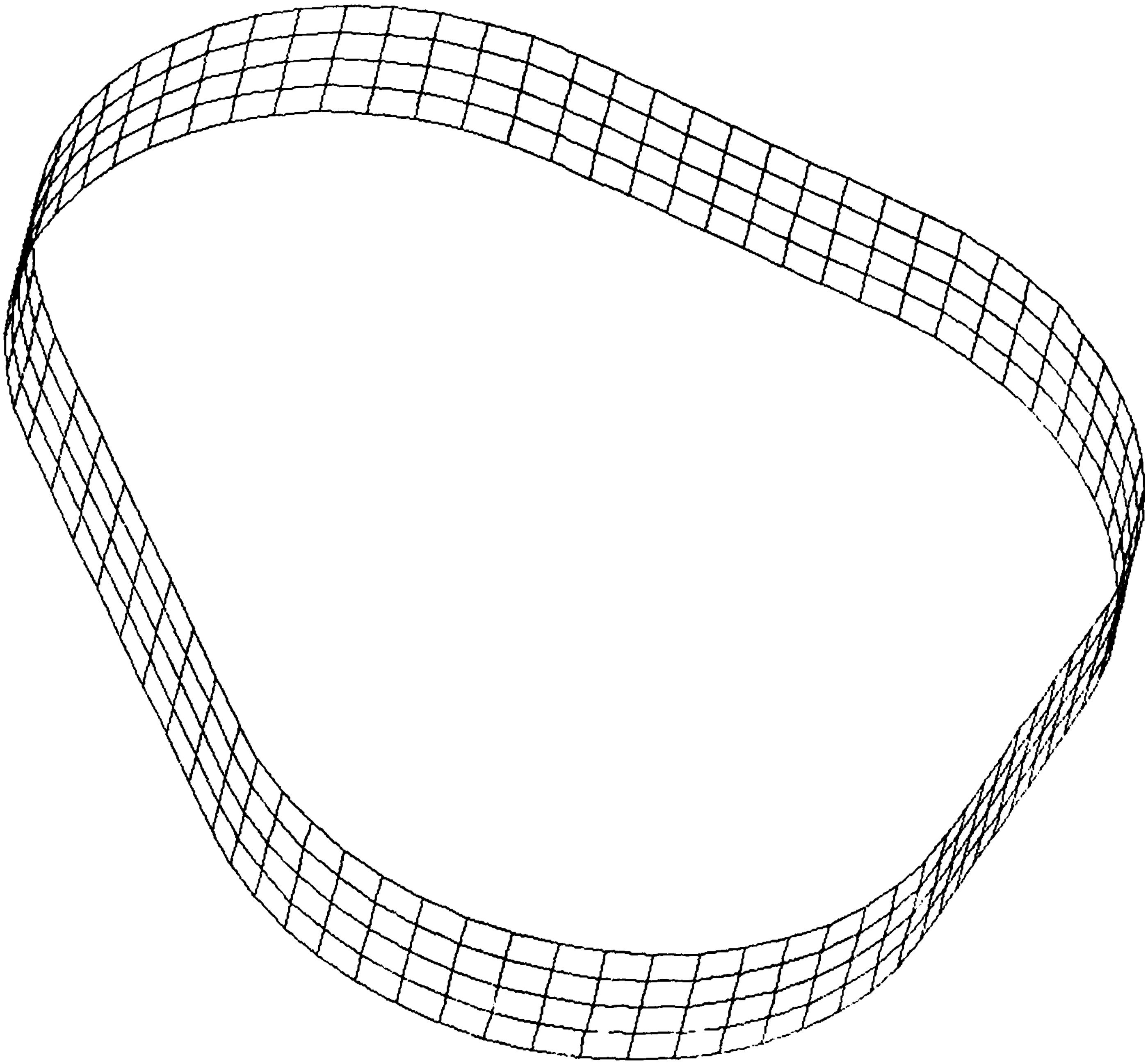
Sample Problem No. 1, Pear Shape Cylinder

PEAR-SHAPED CYLINDER $PL-1

PLOT NO. 2, UNIT 0

MODEL GEOMETRY

MODEL SCALE = .2500E+01, ORIENT. = -15.00, -45.00, -60.00



```
PEAR-SHAPED CYLINDER --- SYMMETRIC MODEL DOWN THE LENGTH $A-1
   1  1  1  0  0  0  1  $B-1
   6  0  0  6  6   $B-2
   1  0  1  $B-3
   1000.0  0.0  1000.0  $C-1
   1  0  9000  $D-2
   2  $D-3
   5,15  5,10  5,20  5,5  5,20  5,10  $F-1  GRID
C
C SHELL UNIT CONNECTIONS
C
   1  2  2  4  $G-1
   2  2  3  4  $G-1
   3  2  4  4  $G-1
   4  2  5  4  $G-1
   5  2  6  4  $G-1
   1  4  6  2  $G-1
C
C MULTI-POINT CONSTRAINTS FOR UNIFORM END-SHORTENING
C
   1  1  1  1    1  1  0  1   $G-2
   1  1  1  1    2  1  0  1   $G-2
   1  1  1  1    3  1  0  1   $G-2
   1  1  1  1    4  1  0  1   $G-2
   1  1  1  1    5  1  0  1   $G-2
   1  1  1  1    6  1  0  1   $G-2
   1  $I-1  MATERIAL DEFINITION
   1.0E+7  0.3  0.0  0.1  $I-2
   1  1  1  $K-1  WALL DEFINITION
   1  0.01  $K-2
C
C UNIT 1  TOP CURVED PANEL
C
   5  3  $M-1
   0.0  0.4  0.0  90.0  1.0  $M-2A
   0.0  -0.7071  -0.2929  $M-4A
   0.0  +0.7071  -0.2929  $M-4B
   0.4  +0.7071  -0.2929  $M-4C
   1  $M-5
   411  $N-1
   1  6  4  6  $P-1
   1  0  0  $Q-1
   1  1  0  $Q-2
   1.0  1  1  1  1  1  $Q-3
   1  $R-1
C
C UNIT 2  LEFT FLAT PANEL
C
   2  3  $M-1
```

```
  0.0  0.4  0.0  1.0  $M-2A
  0.0  0.7071  -0.2929  $M-4A
  0.0  1.4142  -1.0     $M-4B
  0.4  1.4142  -1.0     $M-4C
  1  $M-5
   411  $N-1
  1  6  4  6  $P-1
  0  0  0  $Q-1
  1  $R-1
C
C UNIT 3 LOWER LEFT CURVED PANEL
C
  5  3  $M-1
  0.0  0.4  0.0  135.0  1.0  $M-2A
  0.0  1.4142  -1.0     $M-4A
  0.0  0.7071  -2.7071 $M-4B
  0.4  0.7071  -2.7071 $M-4C
  1  $M-5
  411  $N-1
  1  6  4  6  $P-1
  0  0  0  $Q-1
  1  $R-1
C
C UNIT 4 LOWER FLAT PANEL
C
  2  3  $M-1
  0.0  0.4  0.0  1.4142  $M-2A
  0.0  0.7071  -2.7071  $M-4A
  0.0 -0.7071  -2.7071  $M-4B
  0.4 -0.7071  -2.7071  $M-4C
  1  $M-5
  411  $N-1
  1  6  4  6  $P-1
  0  0  0  $Q-1
  1  $R-1
C
C UNIT 5  LOWER RIGHT CURVED PANEL
C
  5  3  $M-1
  0.0  0.4  0.0  135.0  1.0  $M-2A
  0.0  -0.7071  -2.7071  $M-4A
  0.0  -1.4142  -1.0     $M-4B
  0.4  -1.4142  -1.0     $M-4C
  1  $M-5
  411  $N-1
  1  6  4  6  $P-1
  0  0  0  $Q-1
  1  $R-1
C
```

```
C UNIT 6   RIGHT FLAT PANEL
C
   2   3   $M-1
   0.0   0.4   0.0   1.0   $M-2A
   0.0   -1.4142   -1.0      $M-4A
   0.0   -0.7071   -0.2929  $M-4B
   0.4   -0.7071   -0.2929  $M-4C
   1   $M-5
   411   $N-1
   1   6   4   6   $P-1
   0   0   0   $Q-1
   1   $R-1
```

```
PEAR-SHAPED CYLINDER  $PL-1
  9  1  3.0  0  0  0  $PL-2
  0  $PL-3
  2.50  0.0  0.0  0.0  2.50  $PL-4
  0  $PL-3
   2.50  -15.0  -45.0  -60.0  2.50  $PL-4
   0  $PL-3
   2.50  -90.0  -90.0  0.0  2.50  $PL-4
  1  0  -1  0  1  0  0  3  0  0  0  $PL-3
  2.50  -15.0  -45.0  -60.0  10.0  $PL-4
  1  0  -1  0  4  0  1  3  0  0  -1  $PL-3
  1  0  -1  0  4  0  2  3  0  0  -1  $PL-3
  1  0  -1  0  1  0  0  3  0  0  0  $PL-3
  2.50  -90.0  -90.0  0.0  10.0  $PL-4
  1  0  -1  0  4  0  1  3  0  0  -1  $PL-3
  1  0  -1  0  4  0  2  3  0  0  -1  $PL-3
```

APPENDIX D

BRIEF DESCRIPTION OF USER-WRITTEN SUBROUTINES

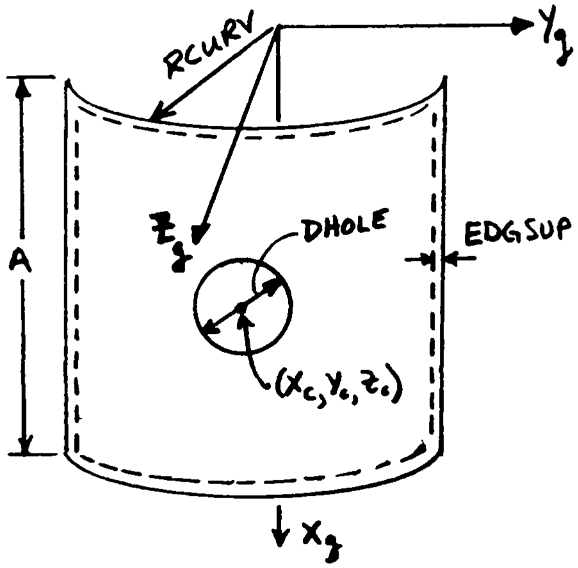
In this Appendix are copies of routines used to analyze the postbuckling response of a graphite-epoxy curved panel with a central circular hole. If the USRELT routine is to be used to define a mesh with quadrilateral elements, then the following common block needs to be included if the default values for INTEG and IPENL are not used:

```
COMMON/QUAFCM/INTGR,INTEG,IPENL,IQRES(7)
```

Brief Description of User-Written Subroutines

These subroutines are used to model the square planform of a panel with a single central circular hole.

The finite element grid is generated using the surface coordinates X and Y. The grid is described using the parameters NRINGS (the number of rings of quadrilateral elements around the hole, assuming that one ring will be for the edge supports if included) and NSPOKES (the number of radial spokes normal to the hole boundary; must be a multiple of 8).



(X_c, Y_c, Z_c) . . Global coordinates of geometric center of panel.

DHOLE . . . Diameter of hole

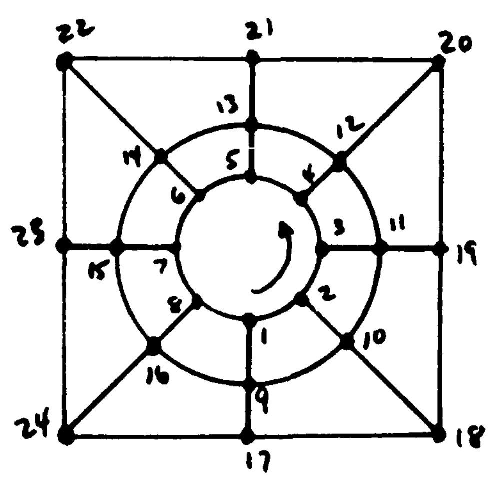
RCURV . . . Radius of curvature of panel (set equal to zero for flat panel)

A . . . . Length of panel

EDGSUP . . Location of edge supports from edge of panel

NODE NUMBERING

The node numbering scheme is counter-clockwise beginning at the edge of the hole as shown:



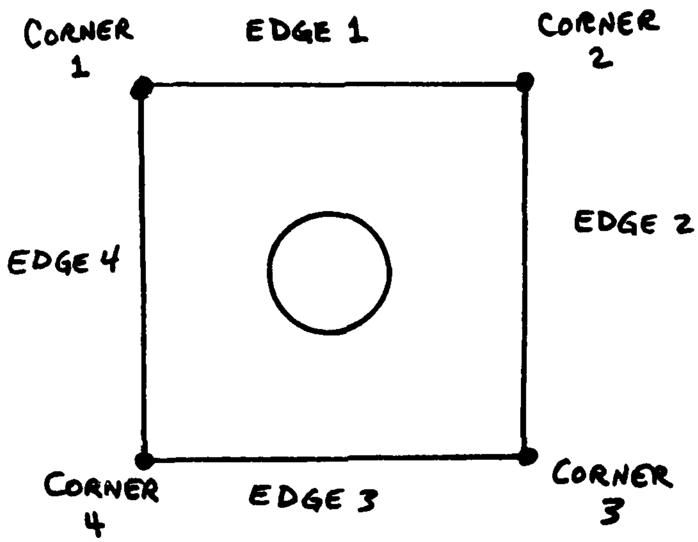
Two additional modeling parameters have been included: MHRCR and RAT.

MHRCR . . . Number of hole radii away from the edge of the hole that the rings of elements will be circular.

RAT . . . . Mesh grading factor. Near zero gives equal spacing of rings and increasing the value of RAT to a maximum of one gives a finer mesh near the hole.

BOUNDARY CONDITIONS

Internal nodes are free. Boundary and corner nodes read in as data.

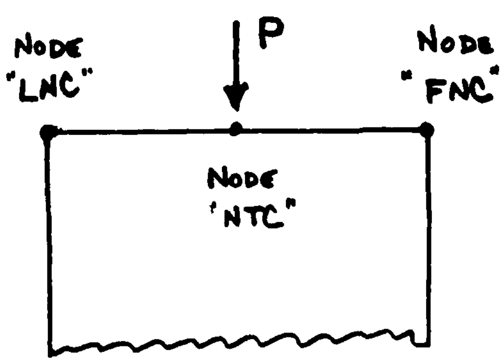


LOADING

Load is applied using a point force at the top (edge 1) center node and applying partial compatability constraints across edge 1.

The node number of top center is given by

NTC = NRINGS * NSPOKES + NSPOKES/2 +1



$U_i = U_{NTC}$

i = FNC, NTC-1

i = NTC + 1, LNC

Where the first nodal constraint is at node number

FNC = NTC - NPC/2

and the last nodal constraint is at node number

LNC = NTC + NPC/2

and NPC = NSPOKES/4 (number of partial compatability constraints)

REQUIRED USER DATA

- User Parameter - Integers

  KQUAD, NRINGS, NSPOKES,

  IUVW IRUVW] repeat for each edge, edges 1, 2, 3, 4

  IUVW IRUVW] repeat for each corner, corners 1, 2, 3, 4

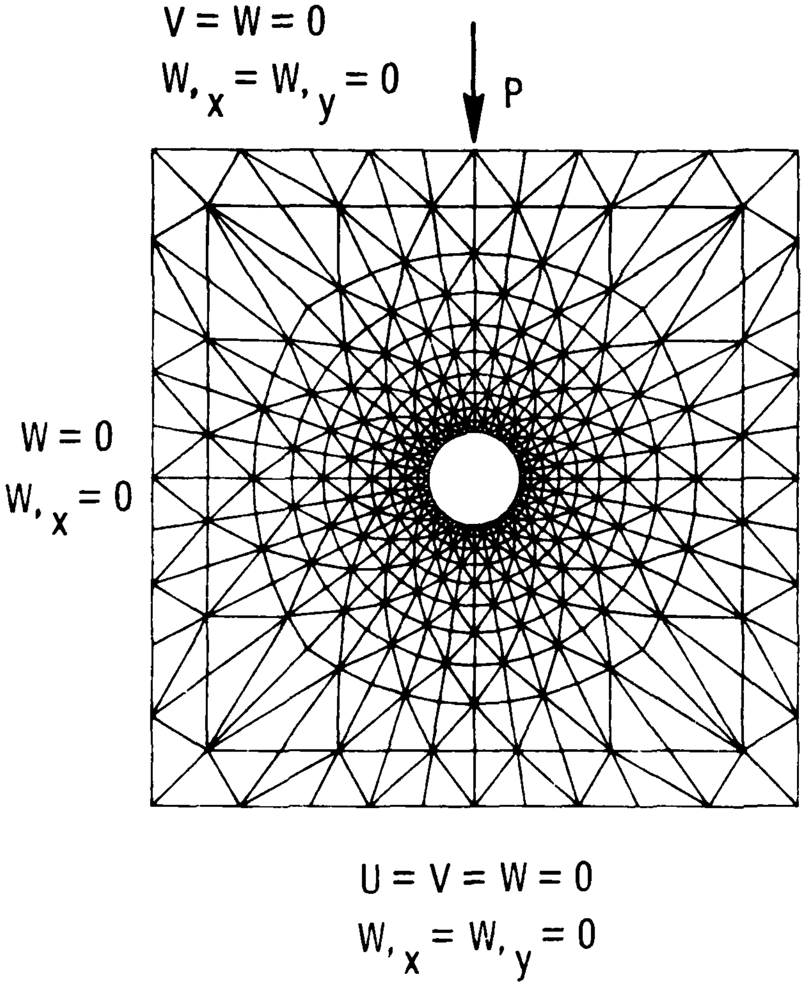
  IWALL, MHRCR

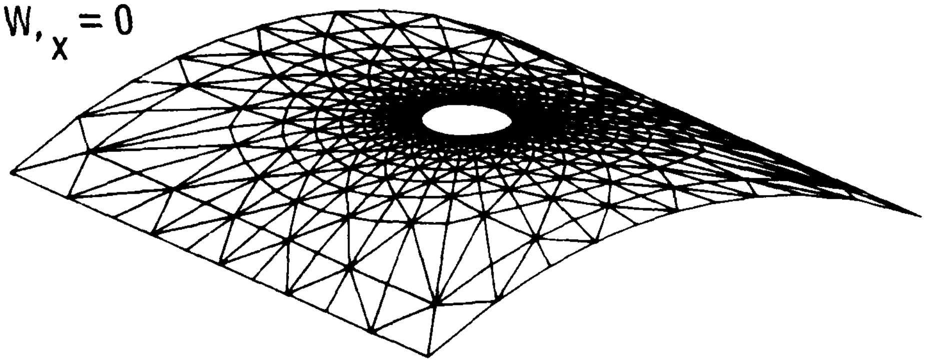
- User Parameters - Floating Point

  A, DHOLE, XC, YC, ZC, RCURV, RAT, EDGSUP

  If EDGSUP = 0, no edge support. *Along the lines of the* edge support W = 0.

FINITE ELEMENT MODEL





- 400 422-TYPE ELEMENTS
- 6175 ACTIVE D.O.F.
- SEMI-BANDWIDTH OF 261

```
      SUBROUTINE USRPT
C
C DEFINE THE NODAL COORDINATES AND DOF
C
      COMMON/UPI/KQUAD,NRINGS,NSPOKES,IBC(16),IWALL,MHRCR
       DIMENSION IUVWB(8),IRUVWB(8),DRAY(96),RRING(96)
C
C KQUAD - ELEMENT TYPE:  IF NEGATIVE, USE REDUCED INTEGRATION
C NRINGS - NUMBER OF INTERNAL RINGS OF NODES AROUND THE HOLE
C NSPOKES - NUMBER OF RADIAL SPOKES NORMAL TO HOLE BOUNDARY
C           (MUST BE A MULTIPLE OF 8)
C IUVWB(1-4) - U,V,W BOUNDARY CONDITIONS ON EDGES OF ELEMENT UNIT
C IUVWB(5-8) - U,V,W BOUNDARY CONDITIONS ON CORNERS OF ELEMENT UNIT
C IRUVWB(1-4) - RU,RV,RW BOUNDARY CONDITIONS ON EDGES OF ELEMENT UNIT
C IRUVWB(5-8) - RU,RV,RW BOUNDARY CONDITIONS ON CORNERS OF ELEMENT UNIT
C IWALL - SELECT SHELL WALL NUMBER FROM THOSE GIVEN BY THE K-CARDS
C MHRCR - MULTIPLE OF HOLE RADII FOR CIRCULAR RINGS OF ELEMENTS
C
      COMMON/PIE/DTR,RTD,PI
      COMMON/UPF/A,DHOLE,XC,YC,ZC,RCURV,RAT,EDGSUP
C
C A  -  LENGTH OR ARC LENGTH OF PANEL (SQUARE PLANFORM)
C DHOLE - DIAMETER OF THE HOLE
C XC,YC,ZC - GLOBAL COORDINATES OF THE CENTER OF THE HOLE
C RCURV - RADIUS OF CURVATURE OF THE PANEL
C         (.EQ.0 => FLAT AND .NE.0 => CURVED )
C RAT - MESH GRADING FACTOR
C       ( NEAR ZERO GIVES EQUAL SPACING OF RINGS;
C         AND AS RAT => 1, FINER MESH NEAR THE HOLE)
C EDGSUP - DISTANCE FROM EDGE OF PANEL TO FIXTURE
C          OR BOUNDARY CONDITIONS OF SUPPORT
C
C
C INITIALIZE
C
      ISYS=0
      IUVW=111
      IRUVW=111
       IF(KQUAD.GE.420) IRUVW=110
      POW=0.0
      IUS=0
      IRS=0
      ICS=0
      RHOLE=0.5*DHOLE
      CRADI=(MHRCR+1)*RHOLE
      DANG=2.0*PI/FLOAT(NSPOKES)
      IF(EDGSUP.LT.0.0) EDGSUP=0.0
      DR=(0.5*A-RHOLE)-EDGSUP
      IF(RAT.LE.0.0) RAT=1.0E-5
      IF(RAT.GT.1.0) RAT=1.0
      RATP1=RAT+1.0
      FACTOR=RAT/(RATP1**NRINGS-1.0)
      PI2=0.5*PI
```

```
      PI4=0.25*PI
C
C UNPACK EDGE AND CORNER BOUNDARY CONDITIONS FROM ARRAY IBC
C
      JBC=1
      DO 10 I=1,16,2
      IUVWB(JBC)=IBC(I)
 10   JBC=JBC+1
C
      JBC=1
      DO 11 I=2,16,2
      IRUVWB(JBC)=IBC(I)
 11   JBC=JBC+1
C
C SET UP FOR MESH GRADING
C
       DR=DR*FACTOR
      DO 50 J=1,NSPOKES
      ANG=(J-1)*DANG
      ANGR=ANG
      IF(ANG.GE.PI2) ANGR=ANG-PI2
      IF(ANG.GE.PI)  ANGR=ANG-PI
      IF(ANG.GE.(3.*PI2)) ANGR=ANG-3.0*PI2
      IF(ANGR.LT.PI4) BETA=(1.0/COS(ANGR)-1.0)
      IF(ANGR.GE.PI4) BETA=(1.0/SIN(ANGR)-1.0)
      DRAY(J)=(1.0+BETA)
      RRING(J)=RHOLE
 50   CONTINUE
C
C DEFINE INTERNAL NODES
C
      NRINGS1=NRINGS-1
      IF(EDGSUP.LE.0.0) NRINGS1=NRINGS
      DO 100 I=1,NRINGS
       IM2=I-2
      IF(I.EQ.NRINGS.AND.EDGSUP.GT.0.0) IUVW=110
      DO 100 J=1,NSPOKES
      IF(I.GT.1.AND.(RRING(1).GT.CRADI))
     .  RRING(J)=RRING(J)+DR*DRAY(J)*RATP1**IM2
      IF(I.GT.1.AND.(RRING(1).LE.CRADI))
     .  RRING(J)=RRING(J)+DR*RATP1**IM2
      RAY=RRING(J)
       IF(I.EQ.NRINGS1) RAY=RRING(1)*DRAY(J)
      IF(I.EQ.NRINGS.AND.EDGSUP.GT.0.0) RAY=(0.5*A-EDGSUP)*DRAY(J)
C
C GLOBAL COORDINATES
C
C (X,Y) ARE SHELL SURFACE COORDINATES AND (XG,YG,ZG) ARE GLOBAL
C COORDINATES
C
       ANG=(J-1)*DANG
      X=RAY*COS(ANG)
      Y=RAY*SIN(ANG)
      XG=XC+X
```

```
      IF(RCURV.GT.0.0) YG=YC+Y
      IF(RCURV.GT.0.0) ZG=RCURV*COS(ASIN(Y/RCURV))
      IF(RCURV.EQ.0.0) YG=YC+Y
      IF(RCURV.EQ.0.0) ZG=ZC
      IUPT=(I-1)*NSPOKES+J
      CALL NODE(IUPT,IUS,IRS,ICS,XG,YG,ZG,IUVW,IRUVW,ISYS,POW)
 100  CONTINUE
C
C DEFINE THE BOUNDARY NODES
C
      NS1=5*NSPOKES/8+1
      NS2=3*NSPOKES/8+1
      NS3R=NSPOKES/8+1
      NS3L=NSPOKES
      NS4=7*NSPOKES/8+1
C
C SET UP EQUAL LENGTH SEGMENTS ALONG EDGES
C
      X=0.0
      Y=0.0
      DO 200 I=1,NSPOKES
      IUPT=NRINGS*NSPOKES+I
      ANG=(I-1)*DANG
      IF(I.LE.NS3R) GO TO 210
      IF(I.GT.NS3R.AND.I.LE.NS2) GO TO 220
      IF(I.GT.NS2.AND.I.LE.NS1) GO TO 230
      IF(I.GT.NS1.AND.I.LE.NS4) GO TO 240
      IF(I.GT.NS4) GO TO 250
C
C RIGHT SIDE OF EDGE 3
C
 210  CONTINUE
      IBCE=3
      IBCC=7
      X=0.5*A
      Y=0.5*A*TAN(ANG)
      IF(I.EQ.NS3R) GO TO 310
      GO TO 320
C
C EDGE 2
C
 220  CONTINUE
      IBCE=2
      IBCC=6
      X=0.5*A*TAN(PI2-ANG)
      Y=0.5*A
      IF(I.EQ.NS2) GO TO 310
      GO TO 320
C
C EDGE 1
C
 230  CONTINUE
```

```
      IBCE=1
      IBCC=5
      X=-0.5*A
      Y=0.5*A*TAN(PI-ANG)
      IF(I.EQ.NS1) GO TO 310
      GO TO 320
C
C EDGE 4
C
 240  CONTINUE
      IBCE=4
      IBCC=8
      X=-0.5*A*TAN(3.*PI2-ANG)
      Y=-0.5*A
      IF(I.EQ.NS4) GO TO 310
      GO TO 320
C
C LEFT SIDE OF EDGE 3
C
 250  CONTINUE
      IBCE=3
      X=0.5*A
      Y=-0.5*A*TAN(2.*PI-ANG)
C
C TRANSFORMATION OF COORDINATES FROM SHELL SURFACE COORDINATES
C TO GLOBAL COORDINATES
C
 320  CONTINUE
      XG=XC+X
      YG=YC+Y
      ZG=ZC
      IF(RCURV.EQ.0.0) GO TO 321
CC    YG=YC+RCURV*SIN(Y/RCURV)
CC    ZG=RCURV*COS(Y/RCURV)
      YG=YC+Y
      ZG=RCURV*COS(ASIN(Y/RCURV))
C
C SET UP THE EDGE NODES
C
 321  CALL NODE(IUPT,IUS,IRS,ICS,XG,YG,ZG,IUVWB(IBCE),IRUVWB(IBCE),
     .ISYS,POW)
      GO TO 200
C
C TRANSFORMATION OF COORDINATES FROM SHELL SURFACE COORDINATES
C TO GLOBAL COORDINATES
C
 310  CONTINUE
      XG=XC+X
      YG=YC+Y
      ZG=ZC
      IF(RCURV.EQ.0.0) GO TO 311


      YG=YC+Y
```

```
     *G-RCURV*COS(ASIN(Y/RCURV))
C
C SET UP THE CORNER EDGE NODES
C
 311  CALL NODE(IUPT,IUS,IRS,ICS,XG,YG,ZG,IUVWB(IBCC),IRUVWB(IBCC),
     .ISYS,POW)
C
 200  CONTINUE
C
C EXIT
C
      RETURN
      END
      SUBROUTINE USRELT
C
C GENERATE THE MESH FOR A SQUARE PLATE WITH A CENTRAL CIRCULAR HOLE
C
      COMMON/UPI/KQUAD,NRINGS,NSPOKES,IUVWB(8),IRUVWB(8),IWALL,MHRCR
C
C KQUAD - ELEMENT TYPE:  IF NEGATIVE, USE REDUCED INTEGRATION
C NRINGS - NUMBER OF INTERNAL RINGS OF NODES AROUND THE HOLE
C NSPOKES - NUMBER OF RADIAL SPOKES NORMAL TO HOLE BOUNDARY
C           (MUST BE A MULTIPLE OF 8)
C IUVWB(1-4) - U,V,W BOUNDARY CONDITIONS ON EDGES OF ELEMENT UNIT
C IUVWB(5-8) - U,V,W BOUNDARY CONDITIONS ON CORNERS OF ELEMENT UNIT
C IRUVWB(1-4) - RU,RV,RW BOUNDARY CONDITIONS ON EDGES OF ELEMENT UNIT
C IRUVWB(5-8) - RU,RV,RW BOUNDARY CONDITIONS ON CORNERS OF ELEMENT UNIT
C IWALL - SELECT SHELL WALL TYPE FROM THOSE GIVEN BY THE K-CARDS
C MHRCR - MULTIPLE OF ROLE RADII FOR CIRCULAR RINGS OF ELEMENTS
C
      COMMON/PIE/DTR,RTD,PI
      COMMON/QUAFCM/INTGR,INTEG,IPENL,IQRES(7)
      DIMENSION ZETA(96)
C
C INITIALIZE
C
      ECZ=0.0
      ILIN=0
      IPLAS=0
      INTEG=0
       IF(KQUAD.LT.0) INTEG=1
       KQUAD=IABS(KQUAD)
      IPENL=0
C
C ORIENTATION ANGLE IN DEGREES
C
      DANG=2.0*PI*RTD/FLOAT(NSPOKES)
      ZETA(1)=0.0
      DO 50 I=2,NSPOKES
      ZETA(I)=ZETA(I-1)+DANG
 50   CONTINUE
C
C FORM THE ELEMENT GRID
C
```

```
      DO 200 I=1,NRINGS
      IODD=0
      IF(MOD(I,2).EQ.1) IODD=1
      DO 100 J=1,NSPOKES
      JODD=0
      IF(MOD(J,2).EQ.1) JODD=1
      N1=(I-1)*NSPOKES +J
      N2=N1+NSPOKES
      N3=N2+1
      N4=N1+1
      IF(J.EQ.NSPOKES) N3=N1+1
      IF(J.EQ.NSPOKES) N4=N3-NSPOKES
       IF(KQUAD.LT.420) GO TO 70
      IF(IODD.EQ.0.AND.JODD.EQ.1) GO TO 75
      IF(IODD.EQ.1.AND.JODD.EQ.0) GO TO 75
 70   CALL QUAD(N1,N2,N3,N4,KQUAD,IWALL,ZETA(J),ECZ,
     .  ILIN,IPLAS)
      GO TO 100
 75   CONTINUE
      ZETAR=ZETA(J)-90.0
      CALL QUAD(N2,N3,N4,N1,KQUAD,IWALL,ZETAR,ECZ,
     .  ILIN,IPLAS)
 100  CONTINUE
 200  CONTINUE
C
C EXIT
C
      RETURN
      END
```

Listings of STAGSC-1 input data and STAPL input data.

```
SQUARE CYLINDRICAL PANEL WITH 2-INCH CENTRAL CIRCULAR HOLE    $A-1
  3   1   1   0   0   1   0   $B-1
  0   1   0   0   10  0   4   $B-2   ELEMENT UNIT ONLY
  2   0   4   29   $B-3
 0.00448  0.0896E-2  0.0896E-3  0.0896E-4   $B-5   IMPERFECTIONS
  0.610192   0.1   2.0   $C-1
 101   15000   20   20   -1   0.00001   $D-1   RIK'S METHOD
  1   421   0   1       1   416   0   1   $G-2   U=CONSTANT AT X=0 CONSTRAINT
  1   421   0   1       1   417   0   1   $G-2
  1   421   0   1       1   418   0   1   $G-2
  1   421   0   1       1   419   0   1   $G-2
  1   421   0   1       1   420   0   1   $G-2
  1   421   0   1       1   422   0   1   $G-2
  1   421   0   1       1   423   0   1   $G-2
  1   421   0   1       1   424   0   1   $G-2
  1   421   0   1       1   425   0   1   $G-2
  1   421   0   1       1   426   0   1   $G-2
  0   0   0   0   0   1   1   $H-1   ONLY USRPT AND USRELT
   1   $I-1   ISOTROPIC MATERIAL
  10.E6   0.3   $I-2
  2   $I-1 QUASI-ISOTROPIC MATERIAL (16 PLY SKIN)
  19.6E6   0.0378 0.93E6 0.01   0.0   1.89E6   0.0   $I-2
  1   1   1   $K-1   SHELL WALL DEFINITION
  1   0.08   0.0   $K-2
  2   1  16$K-1   SHELL WALL
  2   0.005    45.0   $K-2
  2   0.005   -45.0   $K-2
  2   0.005    90.0   $K-2
  2   0.005    0.0   $K-2
  2   0.005   45.0   $K-2
  2   0.005  -45.0   $K-2
  2   0.005   90.0   $K-2
  2   0.005    0.0   $K-2
  2   0.005    0.0   $K-2
  2   0.005   90.0   $K-2
  2   0.005  -45.0   $K-2
  2   0.005   45.0   $K-2
  2   0.005    0.0   $K-2
  2   0.005   90.0   $K-2
  2   0.005  -45.0   $K-2
  2   0.005   45.0   $K-2
  3   4   1   $K-1   D16=D26=0
  0.08   $K-5A WALL THICKNESS
  0.687606E6   0.218464E6   0.   0.   0.   0.   ,   $K-5B
 0.218464E6   0.687606E6   0.   0.   0.   0.   ,   $K-5B
 0.   0.   0.234571E6   0.   0.   0.,   $K-5B
  0.   0.   0.   0.308650E3   0.14549E3   0.   ,$K-5B
  0.   0.   0.   0.145490E3   0.360728E3   0.   ,   $K-5B
  0.   0.   0.   0.   0.   0.157139E3   $K-5B
  4   1  16$K-1   SHELL WALL (+/-45,90,0,0,90,-/+45) SYMMETRIC
  2   0.0056    45.0   $K-2
  2   0.0056   -45.0   $K-2
  2   0.0056    90.0   $K-2
```

```
2  0.0056    0.0  $K-2
2  0.0056    0.0  $K-2
2  0.0056  90.0  $K-2
2  0.0056 -45.0  $K-2
2  0.0056  45.0  $K2
2  0.0056  45.0  $K 2
2  0.0056 -45.0  $K-2
2  0.0056  90.0  $K-2
2  0.0056   0.0  $K-2
2  0.0056    0.0  $K-2
2  0.0056  90.0  $K-2
2  0.0056 -45.0  $K-2
2  0.0056  45.0  $K-2
21  8  $L-1 NUPI+NUPF
422, $L-2A UPI VALUES
10  40,  $L-2A  NRINGS AND NSPOKES
100  000, $L-2A BC ON EDGE 1
110  100, $L-2A BC ON EDGE 2
000  000, $L-2A BC ON EDGE 3
110  100, $L-2A BC ON EDGE 4
100  000, $L-2A BC ON CORNER POINT 1
100  000, $L-2A BC ON CORNER POINT 2
000  000, $L-2A BC ON CORNER POINT 3
000  000, $L-2A BC ON CORNER POINT 4
4,  $L-2A SELECT WALL TYPE
3  $L-2A MULTIPLE OF HOLE RADII FROM HOLE
14.0  2.0  7.0  0.0  15.0  15.0 0.2   0.0 $L-2B UPF VALUES
1  $U-1  LOADS
1  1  0  $U-2
25000.0     1  1  421  0  0  $U-3  POINT LOAD AT NODE 421 X=0
1  0  0  0  0  0  $V-1  OUTPUT FLAGS

SQUARE CYLINDRICAL PANEL WITH 2-INCH CENTRAL CIRCULAR HOLE   $PL-1
53  1  3.0  0  0  0  $PL-2
0  $PL-3
0.25  0.0  0.0  0.0   0.25   $PL-4
0  $PL-3
0.25  -15.0  -45.0  -60.0  0.25  $PL-4
2  1  0  0  1  0  0  1  0  0  0  $PL-3
0.50 90.0  0.0  0.0  100.0   10  $PL-4
2  1   0  0  1  0  0  2  0  0  -1  $PL-3
2  1   0  0  1  0  0  3  0  0  -1  $PL-3
2  1   0  0  1  1  0  3  0  0  -1  $PL-3
2  1   0  0  1  5  0  3  0  0  -1  $PL-3
2  1   0  0  1  10  0  3  0  0  -1  $PL-3
2  1   0  0  1  15  0 3  0  0  -1  $PL-3
2  1   0  0  1  20  0  3  0  0  -1  $PL-3
2  1   0  0  1  25  0  3  0  0  -1  $PL-3
2  1   0  0  1  30  0  3  0  0  -1  $PL-3
2  1   0  0  1  35  0  3  0  0  -1  $PL-3
2  1   0  0  1  40  0  3  0  0  -1  $PL-3
2  1   0  0  1  45  0  3  0  0  -1  $PL-3
2  1   0  0  1  50  0  3  0  0  -1  $PL-3
2  1   0  0  1  55  0  3  0  0  -1  $PL-3
```

```
2  1  0  0  1  60   0  3  0  0  -1  $PL-3
2  1  0  0  1  65   0  3  0  0  -1  $PL-3
2  1  0  0  1  70   0  3  0  0  -1  $PL-3
2  1  0  0  1  75   0  3  0  0  -1  $PL-3
2  1  0  0  1  80   0  3  0  0  -1  $PL-3
2  1  0  0  1  85   0  3  0  0  -1  $PL-3
2  1  0  0  1  90   0  3  0  0  -1  $PL-3
2  1  0  0  1  95   0  3  0  0  -1  $PL-3
2  1  0  0  1  100  0  3  0  0  -1  $PL-3
2  1  0  0  1  105  0  3  0  0  -1  $PL-3
2  1  0  0  1  110  0  3  0  0  -1  $PL-3
2  1  0  0  1  115  0  3  0  0  -1  $PL-3
1  1  0  0  1  1  0  3  0  0  0  $PL-3
0.50  -15.0  -45.0  -60.0  2.50  $PL-4
1  1  0  0  1  5   0  3  0  0  -1  $PL-3
1  1  0  0  1  10  0  3  0  0  -1  $PL-3
1  1  0  0  1  15  0  3  0  0  -1  $PL-3
1  1  0  0  1  20  0  3  0  0  -1  $PL-3
1  1  0  0  1  25  0  3  0  0  -1  $PL-3
1  1  0  0  1  30  0  3  0  0  -1  $PL-3
1  1  0  0  1  35  0  3  0  0  -1  $PL-3
1  1  0  0  1  40  0  3  0  0  -1  $PL-3
1  1  0  0  1  45  0  3  0  0  -1  $PL-3
1  1  0  0  1  50  0  3  0  0  -1  $PL-3
1  1  0  0  1  55  0  3  0  0  -1  $PL-3
1  1  0  0  1  60  0  3  0  0  -1  $PL-3
1  1  0  0  1  65  0  3  0  0  -1  $PL-3
1  1  0  0  1  70  0  3  0  0  -1  $PL-3
1  1  0  0  1  75  0  3  0  0  -1  $PL-3
1  1  0  0  1  80  0  3  0  0  -1  $PL-3
1  1  0  0  1  85  0  3  0  0  -1  $PL-3
1  1  0  0  1  90  0  3  0  0  -1  $PL-3
1  1  0  0  1  95  0  3  0  0  -1  $PL-3
1  1  0  0  1  100  0  3  0  0  -1  $PL-3
1  1  0  0  1  105  0  3  0  0  -1  $PL-3
1  1  0  0  1  110  0  3  0  0  -1  $PL-3
1  1  0  0  1  115  0  3  0  0  -1  $PL-3
```

APPENDIX E

ANNOTATED SAMPLE OUTPUT

INPUT DATA CARDS, PAGE 1

```
CARD NUMBER   ****************************** DATA ************************************
KICUMP4 - KNIGHT, N. TRIGGERING LOAD AND DISPLACEMENT CONTROLED
3 0 0 0 0 0 1  $    (B-1) - NONLINEAR , FULL PRINT OUT
1/1 0 1  $          (B-2,3)- NO. SHELL UNITS=1/ NO. MATLS=1 , NO. SHELL WALLS=1
1. 1. 20. 1. 1. 1. $ (C-1) - LOAD FACTOR = 1. , INCR=1., MAX = 20.
0 750 3 10 $         (D-1) - NEW CASE, 750 CP SEC MAX, 3 LOAD CUTS, 10 REFACTRS
7 7$                 (F-1) - MESH = 7 X 7, I.E. 7 ROWS AND 7 COLUMNS
$
1/19.6+6 .0366 .93+6 0. 0. 1.49+6  $ (I-1,2) - MATERIAL ID/ MATERIAL PROPERTIES
$
1 1 8  $             (K-1) - WALL ID 1, GEN. LAYERED, 8 LAYERS
1 .0056  45. 1    $ (K-2) - MATL ID=1, THICK=.0056, ANGLE=45., PRINT STRESS
1 .0056 -45.      $
1 .0056  90.      $                 REPEAT FOR EACH LAYER
1 .0056   0.
1 .0056   0.
1 .0056  90.
1 .0056 -45.
1 .0056  45. 1
$
2/0. 14. 0. 14./1  $(M-1,2A,5) RECTANGLE/ 14. X 14. PLATE/ WALL ID = 1
411 0 0 0 0 1  $     (N-1) - STANDARD MESH ELEM TYPE=411, REDUCED INTEGRATION
$
0 0 0 0       $       (P-1) - SPECIFY ALL BC S ON (P-2) CARDS
110 011       $       (P-2) - SIDE 1
110 101       $                    2
010 011       $                    3
100 101       $                    4 - RESTRAIN RIGID BODY MOTION IN V DIR
$
2               $   (Q-1) - 2 LOAD SYSTEMS (B FOR TRIGGERING LOAD)
1 1             $   (Q-2)-  LOAD SYS A, NO. OF (Q-3) RECORDS=1
5.E-5  -1  1  1 $(Q-3) - SPEC DISP=5.-5, IN X DIR ON ROW 1
2 1             $   (Q-2) - LOAD SYS B, NO. OF (Q-3) RECS = 1
1.E-3 1 3 4 4 5   (Q-3) - LOAD=1.E-3 IN Z DIR AT ROW 3, COL 3
$ 0. -1  6      $   (Q-3) - ENFORCE 0 RW ROTATION FOR ALL NODES
$
1 2 0 0 0 1 $ (R-1) - OUTPUT CONTROL PRINT DISP, STRESS RESLNTS, POINT FORCES
```

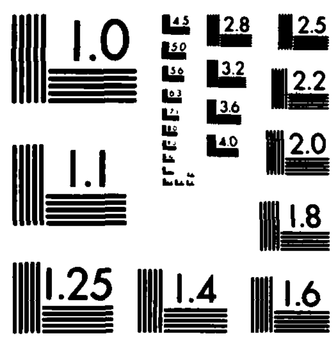
AD-A153 142 SAMPLE PROBLEMS FOR STAGSC-1(U) ANAMET LABS INC SAN CARLOS CA APPLIED MECHANICS DIV P J WOYTOWITZ 28 FEB 85 ANAMET-884.1A AFWAL-TR-84-3088 2/2

UNCLASSIFIED F33615-81-C-3201 F/G 9/2 NL

END

FILMED

DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

```
                         -------------------
                         STAGS-CI / PHASE 1
                         -------------------
```

Preprocessing PHASE

```
                 -----------------------------------------------------------
CASE TITLE  -    KKECMP4 - KNIGHT, W. TRIGGERING LOAD AND DISPLACEMENT CONTROLED
                 -----------------------------------------------------------


COMPUTATIONAL STRATEGY
----------------------
----------------------

- - - NONLINEAR ANALYSIS - - -
      ------------------

               STARTING LOAD FACTOR     STEP LOAD         MAXIMUM LOAD     IXSTF     IXFAC
LOAD FACTOR A    0.1000000E+01        0.1000000E+01      0.2000000E+02       0         0
LOAD FACTOR B    0.1000000E+01        0.1000000E+01      0.1000000E+01

 ISTART   ISEC   ICLT   INEWT   ISTRAT
    0      750     3      10       0

ERROR TOLERANCE =    0.100000E-02 UNDERRELAXATION =    0.000000E+00

MODEL COMPOSITION - ,        1 SHELL UNITS,       0 ELEMENT UNITS

SHELL UNIT SUMMARY
------------------

      UNIT      ROWS    COLS
      ----      ----    ----
        1         7       7

BLANK COMMON BUFFER DIMENSION (NSPACE)
--------------------------------------
      DECIMAL         HEX
       100000        186A0

VIRTUAL MEMORY SPECIFICATIONS
NO. OF PAGES    PAGE SIZE
      18          3583

FM DATA SPACE =   34045,   BLOCK SIZE =   32668

RESOURCE DATA TABLES
--------------------

      TABLE                NO. OF ENTRIES
      -----                --------------
      MATERIAL                     1
      BEAM SECTION                 0
      WALL CONSTRUCTION            1
      USER PARAMETERS              0
      NON-LINEAR MOUNTS            0

      MATERIAL PROPERTY TABLE
      -----------------------
```

(D-1) CARDS

Don't save stiffness Matrix

Don't save Factored stiff. Matrix

Don't worry about this!

ITAM	E1	U12	G	RHC	A1	E2	A2
1	0.19600E+08	0.36000E-01	0.93000E+06	0.00000E+00	0.00000E+00	0.18900E+07	0.00000E+00

(I-1) and (I-2) cards

NO. OF TABULATED MATERIALS (NTAM) = 1

SHELL WALL PROPERTY TABLE

ITAW = 1, GENERAL LAYERED SHELL, KLAY = 8, KLIP = 0

ILAY	MATL	TL	ZETL	LSO
1	1	0.56000E-02	0.45000E+02	1
2	1	0.56000E-02	-0.45000E+02	0
3	1	0.56000E-02	0.90000E+02	0
4	1	0.56000E-02	0.00000E+00	0
5	1	0.56000E-02	0.00000E+00	0
6	1	0.56000E-02	0.90000E+02	0
7	1	0.56000E-02	-0.45000E+02	0
8	1	0.56000E-02	0.45000E+02	1

Print stress for outside layers ONLY

(K-1) + (K-2) CARDS

NO. OF TABULATED WALLS (NTAW) = 1

UNIT 1 (SHELL) - DESCRIPTION

SURFACE GEOMETRY

RECTANGULAR PLATE.

```
X1 =  0.0000E+00   See Fig. 3-9     PROP(5) =  0.0000E+00   (M-1), (M-2A) and
X2 =  0.1400E+02   Ref. [1]         PROP(6) =  0.0000E+00   (M-5) Cards
Y1 =  0.0000E+00                    PROP(7) =  0.0000E+00
Y2 =  0.1400E+02                    PROP(8) =  0.0000E+00
```

GLOBAL ORIENTATION

IGLOBE = 0 - UNIT LOCAL/GLOBAL SYSTEMS COPARALLEL (M-1) card, Local Coordinate System is same as global coor. system

WALL CONSTRUCTION

TABULATED ENTRY	ECCENTRICITY	ORIENTATION
1	0.0000E+00	0.0000E+00 DEG.
	ECZ	ZETA

(M-5) card

DISCRETIZATION

GRIDPOINTS

ROWS	COLS
7	7

X-SPACING
UNIFORM

Y-SPACING
UNIFORM

SHELL ELEMENTS QUAF - 411 } (N-1) card, Element Type see Section 6 Ref. [1]

BOUNDARY LINE	MESH ROW	MESH COL	COORDINATES SURFACE X	Y	COORDINATES GLOBAL CARTESIAN XG	YG	ZG
1	1	1	0.0000	0.0000	0.0000	0.0000	0.0000
1	1	2	0.0000	2.3333	0.0000	2.3333	0.0000
1	1	3	0.0000	4.6667	0.0000	4.6667	0.0000
1	1	4	0.0000	7.0000	0.0000	7.0000	0.0000
1	1	5	0.0000	9.3333	0.0000	9.3333	0.0000
1	1	6	0.0000	11.6667	0.0000	11.6667	0.0000
1	1	7	0.0000	14.0000	0.0000	14.0000	0.0000

See Fig. 2 of this Report

Surface (or local) coordinates coinside with Global Coordinates

BOUNDARY LINE	MESH ROW	MESH COL	SURFACE X	Y	GLOBAL CARTESIAN XG	YG	ZG
2	1	7	0.0000	14.0000	0.0000	14.0000	0.0000
2	2	7	2.3333	14.0000	2.3333	14.0000	0.0000
2	3	7	4.6667	14.0000	4.6667	14.0000	0.0000

2	4	7	7.0000	14.0000	7.0000	14.0000	0.0000
2	5	7	9.3333	14.0000	9.3333	14.0000	0.0000
2	6	7	11.6667	14.0000	11.6667	14.0000	0.0000
2	7	7	14.0000	14.0000	14.0000	14.0000	0.0000

BOUNDARY LINE	MESH ROW	COL	SURFACE X	Y	GLOBAL CARTESIAN XG	YG	ZG
3	7	1	14.0000	0.0000	14.0000	0.0000	0.0000
3	7	2	14.0000	2.3333	14.0000	2.3333	0.0000
3	7	3	14.0000	4.6667	14.0000	4.6667	0.0000
3	7	4	14.0000	7.0000	14.0000	7.0000	0.0000
3	7	5	14.0000	9.3333	14.0000	9.3333	0.0000
3	7	6	14.0000	11.6667	14.0000	11.6667	0.0000
3	7	7	14.0000	14.0000	14.0000	14.0000	0.0000

BOUNDARY LINE	MESH ROW	COL	SURFACE X	Y	GLOBAL CARTESIAN XG	YG	ZG
4	1	1	0.0000	0.0000	0.0000	0.0000	0.0000
4	2	1	2.3333	0.0000	2.3333	0.0000	0.0000
4	3	1	4.6667	0.0000	4.6667	0.0000	0.0000
4	4	1	7.0000	0.0000	7.0000	0.0000	0.0000
4	5	1	9.3333	0.0000	9.3333	0.0000	0.0000
4	6	1	11.6667	0.0000	11.6667	0.0000	0.0000
4	7	1	14.0000	0.0000	14.0000	0.0000	0.0000

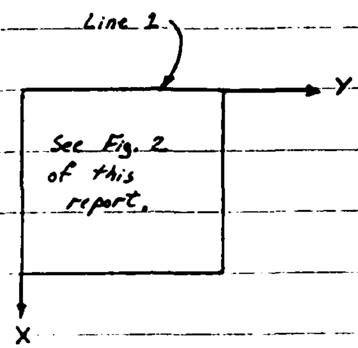
δ_x Free $\quad \delta_y$ Free $\quad$ } θ_y, θ_z Free For Line 2

BOUNDARY CONDITIONS

BOUNDARY CONDITION AT LINE 1 IS SET BY ICOND . ICOND= 1, 1, 0, 0, 1, 1,
BOUNDARY CONDITION AT LINE 2 IS SET BY ICOND . ICOND= 1, 1, 0, 1, 0, 1,
BOUNDARY CONDITION AT LINE 3 IS SET BY ICOND . ICOND= 0, 1, 0, 0, 1, 1,
BOUNDARY CONDITION AT LINE 4 IS SET BY ICOND . ICOND= 1, 0, 0, 1, 0, 1,

} (P-2) Card

$\underbrace{\text{REDUCED 2 X 2 INTEGRATION USED.}}_{\text{(W-1) card}}$



Non linear Geometry

Linear Material

```
SHELL UNIT WALL PROPERTIES (UNIT   1)
---------------------------------------

     X            Y                TYPE            NLAY  NLIP  ISL  ISS  ISD        ZETA          ECZ            ILIN  IPLAS
0.4931E+00   0.4931E+00      GENERAL LAYERED         8     0     0    0    0    0.00000E+00   0.00000E+00          0     0
                                                   LAYER  MATL    THICKNESS        ZETL        LSD
                                                     1      1    0.56000E-02   0.45000E+02     1
                                                     2      1    0.56000E-02  -0.45000E+02     0
                                                     3      1    0.56000E-02   0.90000E+02     0
                                                     4      1    0.56000E-02   0.00000E+00     0
                                                     5      1    0.56000E-02   0.00000E+00     0
                                                     6      1    0.56000E-02   0.90000E+02     0
                                                     7      1    0.56000E-02  -0.45000E+02     0
                                                     8      1    0.56000E-02   0.45000E+02     1
```

(m-5) Record

(k-1) and (k-2) Cards

```
                              CONSTITUTIVE MATRIX,CIJ
                              -----------------------
         (NX)           (NY)           (NXY)           (MX)            (MY)            (MXY)
(EX)   0.395098E+06   0.125650E+06   0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
(EY)                  0.395098E+06   0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
(EXY)                                0.134724E+06   0.000000E+00   0.000000E+00   0.000000E+00
(KX)                                                0.481000E+02   0.326808E+02   0.546192E+01
(KY)                                                               0.607159E+02   0.546142E+01
(KXY)                                                                             0.342064E+02

UNIT  1 PRE-PROCESSING SUMMARY
------------------------------

      ELEMENTS     GEOMETRIC RELS    CONSTITUTIVE RELS    WEIGHT INCREMENT     NEW GROSS WEIGHT
      --------     --------------    -----------------    ----------------     ----------------
      SHLL 411       NONLINEAR            ELASTIC            0.0000E+00           0.0000E+00

UNIT     1 LOAD,SUMMARY
-----------------------

  LOAD SYSTEMS      INITIAL CONDITIONS      ATTACHED MASSES      PRESTRESS
          NSYS                    NICS                NAMAS          NPRST
             2                       0                    0              0
```

$\varepsilon_x = \frac{\partial u}{\partial x}$, $\varepsilon_y = \frac{\partial v}{\partial y}$,

$\varepsilon_{xy} = \frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}$

$\chi_x = -\frac{\partial^2 w}{\partial x^2}$, $\chi_y = -\frac{\partial^2 w}{\partial y^2}$

$\chi_{xy} = -2\frac{\partial^2 w}{\partial x \partial y}$

Then:

$$\begin{Bmatrix} N_x \\ N_y \\ \vdots \\ M_{xy} \end{Bmatrix} = \begin{bmatrix} C_{11} & C_{12} & \cdots \\ & \ddots & \\ & & C_{66} \end{bmatrix} \begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \vdots \\ \chi_{xy} \end{Bmatrix}$$

Number of load Systems

No initial conditions (statics)

No MASS

No UNIFORM Prestress B.C.

```
LOAD A DATA
-----------
       P               I    N   ROW   COL    LAX
0.5000000E-04         -1    1    1     0     SHELL
```

Load direction is x

Load Defined in Shell coordinate system x', y', z'.

Apply displacement to all columns of Row 1

```
LOAD B DATA
-----------
       P               I    N   ROW   COL    LAX
0.1000000E-02          1    3    4     4     SHELL
```

Specified Displacement (e-3) card

```
OUTPUT CONTROL PARAMETERS / UNIT NO.     1
    DISPL   STRS RESLL    STRAINS    STRESSES    PLAS STR    REACTIONS
    IPRD        IPRR        IPRE        IPRS       IPRP         IPRF
```

see (R-1) card

```
                1           2             0              0             0            1   } (R-1) card
CP SEC.=   16.380,  I/O REQSTS.=     1.  WORDS USED=    2048.  WORDS TRANSFD.=   2.000000D+03
SPACE NEEDS
 NEED   IN1    IN2    INL NUMND  IADJ    NIA NXTRA
 2756 65955 98625 98625    49 98724    312  2000

MATRIX PROFILE MINIMIZATION
TOTAL NODES   SHELL NODES  ELEMENT NODES   CONSTRAINTS   CONNECTIVITY TABLES
        49            49              0             0                   312
```

not important!

COMPUTATIONAL DOF ASSIGNMENTS

UNIT	ROW	COL	U	V	W	RL	RV	RW		MID1	MID2	MID3
1	1	1	1	0	0	0	0	2	0	3	4	
1	1	2	5	6	0	0	7	8	9	10	11	
1	1	3	12	13	0	0	14	15	16	17	18	
1	1	4	19	20	0	0	21	22	23	24	25	
1	1	5	26	27	0	0	28	29	30	31	32	
1	1	6	33	34	0	0	35	36	37	38	39	
1	1	7	40	41	0	0	0	42	43	44		
1	2	1	45	0	0	46	0	47	0	48	49	
1	2	2	50	51	52	53	54	55	56	57	58	
1	2	3	59	60	61	62	63	64	65	66	67	
1	2	4	68	69	70	71	72	73	74	75	76	
1	2	5	77	78	79	80	81	82	83	84	85	
1	2	6	86	87	88	89	90	91	92	93	94	
1	2	7	95	96	0	97	0	98	99	100		
1	3	1	101	0	0	102	0	103	0	104	105	
1	3	2	106	107	108	109	110	111	112	113	114	
1	3	3	115	116	117	118	119	120	121	122	123	
1	3	4	124	125	126	127	128	129	130	131	132	
1	3	5	133	134	135	136	137	138	139	140	141	
1	3	6	142	143	144	145	146	147	148	149	150	
1	3	7	151	152	0	153	0	154	155	156		
1	4	1	157	0	0	158	0	159	0	160	161	
1	4	2	162	163	164	165	166	167	168	169	170	
1	4	3	171	172	173	174	175	176	177	178	179	
1	4	4	180	181	182	183	184	185	186	187	188	
1	4	5	189	190	191	192	193	194	195	196	197	
1	4	6	198	199	200	201	202	203	204	205	206	
1	4	7	207	208	0	209	0	210	211	212		
1	5	1	213	0	0	214	0	215	0	216	217	
1	5	2	218	219	220	221	222	223	224	225	226	
1	5	3	227	228	229	230	231	232	233	234	235	
1	5	4	236	237	238	239	240	241	242	243	244	
1	5	5	245	246	247	248	249	250	251	252	253	
1	5	6	254	255	256	257	258	259	260	261	262	
1	5	7	263	264	0	265	0	266	267	268		
1	6	1	269	0	0	270	0	271	0	272	273	
1	6	2	274	275	276	277	278	279	280	281	282	
1	6	3	283	284	285	286	287	288	289	290	291	
1	6	4	292	293	294	295	296	297	298	299	300	
1	6	5	301	302	303	304	305	306	307	308	309	
1	6	6	310	311	312	313	314	315	316	317	318	
1	6	7	319	320	0	321	0	322	323	324		

a "0" indicates that the degree of freedom is constrained (fixed), otherwise the number indicates the equation number

```
COMPUTATIONAL DOF ASSIGNMENTS
-----------------------------

 UNIT  ROW  COL        U     V     W    RU    RV    RW                 MID1  MID2  MID3
   1    7    1         0     0     0     0     0     0     0          325
   1    7    2         0   326     0     0   327     0   328          329
   1    7    3         0   330     0     0   331     0   332          333
   1    7    4         0   334     0     0   335     0   336          337
   1    7    5         0   338     0     0   339     0   340          341
   1    7    6         0   342     0     0   343     0   344          345
   1    7    7         0   346     0     0     0     0   347
CP SEC.=   18.000.  I/O REQSTS.=     2.  WORDS USED=    34816.  WORDS TRANSFD.=   3.46700D+04

PREPROCESSING SUMMARY
---------------------
NO. OF UNITS     NO. OF D.O.F. (TOTAL)       NO. OF D.O.F. (ACTIVE)
      1                         595                            347

 => * COMPUTATIONAL STATISTICS

      EQUATIONS .................        347
      AVG. HALF-BANDWIDTH .......         52
      NONZERO STIFFNESSES .......      18066
      EST. FLOATING OPERATONS ...     517824
      EST. FACTORIZATION TIME ....0.821739E+01 SECS

STAGS1 MASS STORAGE STATISTICS
------------------------------
   FILE NAME     FILE LENGTH    FILE FUNCTION
        1            2705       CONFIGURATION
        2             858       DOF ASSIGNMENT
        3             713       LOADS
        4             662       MASSES
        5              73       RESOURCES
      FMDATA        32668       VARIATION DATA
      FMDATA         3470       GLOBAL VECTORS

CALCULATION OF ELEMENT INTERPOLATION AND CONSTITUTIVEMATRICES COMPLETE.
CP SEC.=   21.940.  I/O REQSTS.=    33.  WORDS USED=    58496.  WORDS TRANSFD.=   1.82950D+05
```

Not important!

$\boxed{\text{END OF PREPROCESSING PHASE}}$

```
STAGS-C1  DEC-92  VAX

        --------------------------
        SOLUTION PHASE  (STAGS2)
        --------------------------

CASE TITLE READ FROM STAGS1 FILE
---------------------------------

        -----------------------------------------------------------------
        KNCUMP4 - KNIGHT, N. TRIGGERING LOAD AND DISPLACEMENT CONTROLED
        -----------------------------------------------------------------

  14 RECORDS READ FROM FT02
BLANK COMMON BUFFER DIMENSION (NSPACE)
-------------------------------------
  DECIMAL          HEX
  140000          222E0

WORKING SPACE STORAGE ASSIGNMENTS
   NEQ  VMBUFR  PAGESZ  NPAGE  FMBUFR  NAMCD  NMTRX  ASTIFF  NASSEM
   347   25088    3584      7  114646  32668  37232       2      12

ELEMENT STIFFNESS MATRICES COMPUTED FOR UNIT     1 (SHELL)
CP SEC.=   20.520.  I/O REQSTS.=      22.  WCRDS USED=    58496.  WORDS TRANSFD.=   1.033120+05

 ASSEMBLY OF TOTAL STIFFNESS MATRIX COMPLETED.
CP SEC.=   22.150.  I/O REQSTS.=      22.  WCRDS USED=    58496.  WORDS TRANSFD.=   1.033120+05

SMALLEST MAIN DIAGONAL AFTER FACTORIZATION
 D.O.F          VALUE
  343  0.121194E-01
                                              See Section 1.3.2 of this Report
DETERMINANT OF STIFFNESS MATRIX=    0.3186022E-07*10.**  -110.   NUMBER OF NEGATIVE ROOTS =   0
     347 EQUATIONS, AVERAGE BAND WIDTH =            51
MATRIX DECOMPOSITION COMPLETED.
CP SEC.=   33.280.  I/O REQSTS.=      22.  WCRDS USED=    58496.  WORDS TRANSFD.=   1.033120+05

          STRAIN ENERGY =        0.296323E-02
CP SEC.=   41.540.  I/O REQSTS.=      27.  WCRDS USED=    58496.  WORDS TRANSFD.=   1.416530+05
```

UNIT 1 (SHELL)

DISPLACEMENTS

STEP 0

PA = 0.1000E+01
PB = 0.1000E+01

- - - - LINEAR SOLUTION - - - - } No geometric nonlinearity yet !

ROW	COL	X	Y	U	V	W	RU	RV	RW1	RW2
1	1	0.000	0.000	5.0000E-05	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	3.6911E-05	
1	2	0.000	2.333	5.0000E-05	3.5148E-06	0.0000E+00	0.0000E+00	-3.2558E-06	1.6400E-05	-2.4050E-06
1	3	0.000	4.667	5.0000E-05	5.0249E-06	0.0000E+00	0.0000E+00	-4.9971E-06	7.2076E-06	-3.2580E-07
1	4	0.000	7.000	5.0000E-05	6.4817E-06	0.0000E+00	0.0000E+00	-5.3593E-06	9.4973E-07	1.2244E-06
1	5	0.000	9.333	5.0000E-05	9.5230E-06	0.0000E+00	0.0000E+00	-4.0131E-06	-6.7938E-06	-2.6766E-06
1	6	0.000	11.667	5.0000E-05	6.6485E-06	0.0000E+00	0.0000E+00	-1.9458E-06	-1.3355E-05	1.1474E-05
1	7	0.000	14.000	5.0000E-05	1.8586E-05	0.0000E+00	0.0000E+00	0.0000E+00	-4.5727E-05	-1.6464E-05

ROW	COL	X	Y	U	V	W	RU	RV	RW1	RW2
2	1	2.333	0.000	3.6027E-05	0.0000E+00	0.0000E+00	3.2853E-06	0.0000E+00	2.7210E-06	
2	2	2.333	2.333	4.0058E-05	2.2179E-06	6.8077E-06	2.5475E-06	-2.5793E-06	5.7277E-06	-8.3415E-07
2	3	2.333	4.667	4.1144E-05	4.6712E-06	1.1305E-05	1.2953E-06	-4.6914E-06	3.7022E-06	-1.2066E-07
2	4	2.333	7.000	4.1437E-05	7.0261E-06	1.2381E-05	-3.9884E-07	-5.2482E-06	6.0764E-07	3.7071E-07
2	5	2.333	9.333	4.1112E-05	9.4166E-06	9.8185E-06	-1.7690E-06	-4.3973E-06	-2.3992E-06	6.5714E-07
2	6	2.333	11.667	3.9568E-05	1.1619E-05	5.0348E-06	-2.3199E-06	-2.3657E-06	-3.5763E-06	3.0836E-06
2	7	2.333	14.000	3.1794E-05	1.3540E-05	0.0000E+00	-1.9901E-06	0.0000E+00	3.8592E-06	2.3576E-06

ROW	COL	X	Y	U	V	W	RU	RV	RW1	RW2
3	1	4.667	0.000	3.1327E-05	0.0000E+00	0.0000E+00	5.1135E-06	0.0000E+00	4.6605E-06	
3	2	4.667	2.333	3.1979E-05	2.2840E-06	1.1476E-05	4.7177E-06	-1.4112E-06	2.8159E-06	-2.7845E-07
3	3	4.667	4.667	3.2624E-05	4.7990E-06	2.0802E-05	3.2559E-06	-3.4319E-06	1.7144E-06	1.7289E-08
3	4	4.667	7.000	3.2845E-05	7.4523E-06	2.4152E-05	-4.3699E-07	-4.8263E-06	4.5556E-07	3.7736E-07
3	5	4.667	9.333	3.2457E-05	1.0233E-05	1.9364E-05	-3.6115E-06	-3.7696E-06	-7.9363E-07	7.9156E-07
3	6	4.667	11.667	3.1283E-05	1.3082E-05	9.9817E-06	-4.4113E-06	-1.8654E-06	-1.8916E-06	1.3268E-06
3	7	4.667	14.000	3.0425E-05	1.5947E-05	0.0000E+00	-4.1362E-06	0.0000E+00	-5.8061E-06	-8.4659E-07

ROW	COL	X	Y	U	V	W	RU	RV	RW1	RW2
4	1	7.000	0.000	2.3418E-05	0.0000E+00	0.0000E+00	5.5241E-06	0.0000E+00	1.2114E-06	
4	2	7.000	2.333	2.3950E-05	2.4037E-06	1.2671E-05	5.3286E-06	4.1177E-07	1.2188E-06	-5.8432E-08
4	3	7.000	4.667	2.4312E-05	5.0051E-06	2.4346E-05	4.6585E-06	4.4614E-07	8.1199E-07	1.0587E-07
4	4	7.000	7.000	2.4396E-05	7.7462E-06	2.9863E-05	5.9221E-13	-6.2174E-13	3.0660E-07	3.5222E-07
4	5	7.000	9.333	2.4045E-05	1.0540E-05	2.4346E-05	-4.6585E-06	-4.4614E-07	-1.9887E-07	5.9034E-07
4	6	7.000	11.667	2.3314E-05	1.3209E-05	1.2671E-05	-5.3286E-06	-4.1177E-07	-6.7246E-07	7.2451E-07
4	7	7.000	14.000	2.2229E-05	1.5590E-05	0.0000E+00	-5.5241E-06	0.0000E+00	-1.6779E-07	6.6005E-07

ROW	COL	X	Y	U	V	W	RU	RV	RW1	RW2
5	1	9.333	0.000	1.5834E-05	0.0000E+00	0.0000E+00	4.1362E-06	0.0000E+00	7.8348E-07	
5	2	9.333	2.333	1.5993E-(	2.5381E-06	9.9817E-06	4.4113E-06	1.8654E-06	5.9208E-07	1.3485E-08
5	3	9.333	4.667	1.6145E-05	5.1736E-06	1.9364E-05	3.6115E-06	3.7696E-06	4.0227E-07	1.4128E-07
5	4	9.333	7.000	1.6149E-05	7.8951E-06	2.4152E-05	4.3699E-07	4.8263E-06	1.8462E-07	[illegible]
5	5	9.333	9.333	1.5922E-05	1.0620E-05	2.0802E-05	-3.2559E-06	3.4319E-06	-5.0047E-08	4.7858E-07
5	6	9.333	11.667	1.5548E-05	1.3241E-05	1.1476E-05	-4.7177E-06	1.4112E-06	-3.0223E-07	5.4537E-07

UNIT 1 (SHELL) DISPLACEMENTS STEP 0

ROW	COL	X	Y	U	V	W	RU	RV	RW1	RW2
5	7	9.333	14.000	1.5354E-05	1.5739E-05	0.0000E+00	-5.1135E-06	0.0000E+00	-8.5335E-07	3.2209E-07
6	1	11.667	0.000	7.9295E-06	0.0000E+00	0.0000E+00	1.9901E-06	0.0000E+00	2.5603E-07	
6	2	11.667	2.333	8.0000E-06	2.5985E-06	5.0348E-06	2.3199E-06	2.3657E-06	2.2891E-07	3.4702E-08
6	3	11.667	4.667	8.0540E-06	5.2554E-06	9.8185E-06	1.7690E-06	4.3973E-06	1.6551E-07	1.4179E-07
6	4	11.667	7.000	8.0417E-06	7.9519E-06	1.2381E-05	3.9684E-07	5.2482E-06	8.7204E-08	2.9460E-07
6	5	11.667	9.333	7.9324E-06	1.0621E-05	1.1305E-05	-1.2953E-06	4.6914E-06	-2.8254E-10	4.3224E-07
6	6	11.667	11.667	7.7724E-06	1.3193E-05	6.8077E-06	-2.5475E-06	2.5793E-06	-9.1491E-08	4.9041E-07
6	7	11.667	14.000	7.6353E-06	1.5651E-05	0.0000E+00	-3.2853E-06	0.0000E+00	-8.9712E-08	4.8751E-07
7	1	14.000	0.000	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	
7	2	14.000	2.333	0.0000E+00	2.6103E-06	0.0000E+00	0.0000E+00	1.9456E-06	0.0000E+00	2.2002E-08
7	3	14.000	4.667	0.0000E+00	5.2732E-06	0.0000E+00	0.0000E+00	4.0131E-06	0.0000E+00	1.2215E-07
7	4	14.000	7.000	0.0000E+00	7.9676E-06	0.0000E+00	0.0000E+00	5.3593E-06	0.0000E+00	2.8092E-07
7	5	14.000	9.333	0.0000E+00	1.0629E-05	0.0000E+00	0.0000E+00	4.9971E-06	0.0000E+00	4.3142E-07
7	6	14.000	11.667	0.0000E+00	1.3192E-05	0.0000E+00	0.0000E+00	3.2558E-06	0.0000E+00	4.9774E-07
7	7	14.000	14.000	0.0000E+00	1.5659E-05	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	4.6978E-07

See Section 6, Table 6.3.1 of [1] for description of RW1 and RW2.

UNIT 1 (SHELL)

EQUILIBRIUM FORCES

STEP 0

PA = 0.1000E+01
PM = 0.1000E+01

- - - - LINEAR SOLUTION - - - -

Each force should ≈ 0 unless a load or boundary condition is present @ the particular row and column

ROW	COL	X	Y	U	V	W	RU	RV	RW1	RW2
1	1	0.000	0.000	7.9359E-01	6.7194E-02	1.6357E-04	-1.8087E-05	3.5570E-05	8.4568E-17	-2.1187E-01
1	2	0.000	2.333	3.1151E+00	0.0000E+00	-1.5972E-07	1.0482E-04	0.0000E+00	0.0000E+00	0.0000E+00
1	3	0.000	4.667	2.9714E+00	0.0000E+00	-2.2509E-05	2.6217E-04	0.0000E+00	0.0000E+00	0.0000E+00
1	4	0.000	7.000	3.0118E+00	0.0000E+00	-4.3966E-04	-1.9776E-05	0.0000E+00	0.0000E+00	0.0000E+00
1	5	0.000	9.333	2.9235E+00	0.0000E+00	2.8362E-05	-2.7874E-04	0.0000E+00	0.0000E+00	0.0000E+00
1	6	0.000	11.667	3.5687E+00	0.0000E+00	1.1450E-05	-1.1833E-04	0.0000E+00	0.0000E+00	0.0000E+00
1	7	0.000	14.000	4.2158E-01	-5.2981E-17	1.8304E-04	-5.6669E-05	-4.6953E-05	-3.5453E-17	-6.0715E-17

ACCUMULATED FORCES FOR ROW 1, X = 0.00000

U	V	W	RU	RV	RW1	RW2
1.6806E+01	6.7194E-02	-7.5904E-05	-1.2460E-04	-1.1583E-05	4.9114E-17	-2.1187E-01

ROW	COL	X	Y	U	V	W	RU	RV	RW1	RW2
2	1	2.333	0.000	0.0000E+00	-2.5740E-01	7.7907E-07	0.0000E+00	-7.6141E-05	0.0000E+00	2.7865E-01
2	2	2.333	2.333	0.0000E+00	-1.1176E-08	1.4552E-11	-7.2760E-12	0.0000E+00	-2.9802E-08	2.7940E-09
2	3	2.333	4.667	0.0000E+00	0.0000E+00	0.0000E+00	-1.4552E-11	0.0000E+00	0.0000E+00	4.6566E-10
2	4	2.333	7.000	-1.1921E-07	0.0000E+00	0.0000E+00	-1.4552E-11	0.0000E+00	0.0000E+00	-1.1642E-10
2	5	2.333	9.333	-1.1921E-07	-3.7253E-09	0.0000E+00	1.0914E-11	2.2737E-13	0.0000E+00	-2.3283E-09
2	6	2.333	11.667	0.0000E+00	0.0000E+00	-1.4552E-11	7.0486E-12	3.6380E-12	0.0000E+00	0.0000E+00
2	7	2.333	14.000	0.0000E+00	0.0000E+00	1.1309E-05	0.0000E+00	-8.9437E-05	0.0000E+00	0.0000E+00

ROW	COL	X	Y	U	V	W	RU	RV	RW1	RW2
3	1	4.667	0.000	0.0000E+00	1.9252E-01	-2.4426E-05	0.0000E+00	-2.4651E-04	0.0000E+00	-7.3723E-02
3	2	4.667	2.333	-1.1921E-07	0.0000E+00	0.0000E+00	-3.6380E-12	0.0000E+00	0.0000E+00	-4.6566E-10
3	3	4.667	4.667	0.0000E+00	-3.7253E-09	0.0000E+00	0.0000E+00	0.0000E+00	-5.9605E-08	9.3132E-10
3	4	4.667	7.000	0.0000E+00	9.3132E-10	2.9104E-11	-7.2760E-12	7.2760E-12	0.0000E+00	1.8626E-09
3	5	4.667	9.333	0.0000E+00	3.7835E-09	.0000E+00	-7.2760E-12	7.2760E-12	0.0000E+00	0.0000E+00
3	6	4.667	11.667	-1.1921E-07	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	5.9605E-08	-1.8626E-09
3	7	4.667	14.000	0.0000E+00	0.0000E+00	3.4835E-05	0.0000E+00	-2.5591E-04	0.0000E+00	0.0000E+00

ROW	COL	X	Y	U	V	W	RU	RV	RW1	RW2
4	1	7.000	0.000	0.0000E+00	2.4937E-02	-4.4659E-04	0.0000E+00	1.7004E-05	0.0000E+00	1.1784E-02
4	2	7.000	2.333	-1.1921E-07	3.7253E-09	0.0000E+00	0.0000E+00	1.4552E-11	5.9605E-08	4.6566E-10
4	3	7.000	4.667	-1.1921E-07	3.7253E-09	0.0000E+00	0.0000E+00	1.4552E-11	0.0000E+00	0.0000E+00
4	4	7.000	7.000	-1.1921E-07	0.0000E+00	1.0000E-03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
4	5	7.000	9.333	-1.1921E-07	9.3132E-10	1.4552E-11	0.0000E+00	2.9104E-11	-5.9605E-08	9.3132E-10
4	6	7.000	11.667	-1.1921E-07	0.0000E+00	1.4552E-11	-3.6380E-12	0.0000E+00	0.0000E+00	-2.3283E-10
4	7	7.000	14.000	0.0000E+00	0.0000E+00	-4.4659E-04	0.0000E+00	-1.7004E-05	0.0000E+00	0.0000E+00

ROW	COL	X	Y	U	V	W	RU	RV	RW1	RW2
5	1	9.333	0.000	0.0000E+00	7.1125E-03	3.4835E-05	0.0000E+00	2.5591E-04	0.0000E+00	-8.6397E-03
5	2	9.333	2.333	0.0000E+00	0.0000E+00	0.0000E+00	4.4906E-12	4.5475E-13	5.9605E-08	0.0000E+00
5	3	9.333	4.667	-1.1921E-07	3.7253E-09	0.0000E+00	2.1828E-11	0.0000E+00	0.0000E+00	9.3132E-10

UNIT 1 (SHELL) EQUILIBRIUM FORCES STEP 0

ROW	COL	X	Y	U	V	W	RU	RV	RW1	RW2
5	4	9.333	7.000	0.0000E+00	0.0000E+00	-1.4552E-11	0.0000E+00	3.6380E-12	-5.9605E-08	0.0000E+00
5	5	9.333	9.333	-1.1921E-07	-2.0955E-09	0.0000E+00	-7.2760E-12	0.0000E+00	-5.9605E-08	9.3132E-10
5	6	9.333	11.667	-1.1921E-07	-1.8626E-09	1.4552E-11	0.0000E+00	1.4552E-11	0.0000E+00	0.0000E+00
5	7	9.333	14.000	0.0000E+00	0.0000E+00	-2.4426E-05	0.0000E+00	2.4651E-04	0.0000E+00	0.0000E+00

ROW	COL	X	Y	U	V	W	RU	RV	RW1	RW2
6	1	11.667	0.000	0.0000E+00	-2.1958E-02	1.1309E-05	0.0000E+00	8.9437E-05	0.0000E+00	-1.1563E-03
6	2	11.667	2.333	-2.3842E-07	1.8626E-09	-1.4552E-11	3.6380E-12	2.7285E-12	0.0000E+00	9.3132E-10
6	3	11.667	4.667	-1.1921E-07	3.7253E-09	0.0000E+00	-1.4552E-11	1.8190E-12	0.0000E+00	0.0000E+00
6	4	11.667	7.000	1.1921E-07	3.7253E-09	0.0000E+00	-1.4552E-11	0.0000E+00	0.0000E+00	0.0000E+00
6	5	11.667	9.333	-1.1921E-07	-9.3132E-10	0.0000E+00	-7.2760E-12	0.0000E+00	0.0000E+00	0.0000E+00
6	6	11.667	11.667	-1.1921E-07	-3.4925E-10	0.0000E+00	0.0000E+00	2.7285E-12	0.0000E+00	-4.6566E-10
6	7	11.667	14.000	0.0000E+00	0.0000E+00	7.7909E-07	0.0000E+00	7.6141E-05	0.0000E+00	0.0000E+00

ROW	COL	X	Y	U	V	W	RU	RV	RW1	RW2
7	1	14.000	0.000	-1.3994E+00	-1.2410E-02	1.8304E-04	5.6669E-05	4.6953E-05	5.4561E-01	4.7501E-03
7	2	14.000	2.333	-2.8274E+00	0.0000E+00	-1.1450E-05	-1.1833E-04	0.0000E+00	-2.3742E-03	0.0000E+00
7	3	14.000	4.667	-2.8376E+00	0.0000E+00	2.8362E-05	2.7874E-04	0.0000E+00	-2.6718E-03	0.0000E+00
7	4	14.000	7.000	-2.8295E+00	0.0000E+00	-4.3966E-04	1.9775E-05	0.0000E+00	-3.7348E-03	0.0000E+00
7	5	14.000	9.333	-2.7971E+00	0.0000E+00	-2.2509E-05	-2.6217E-04	0.0000E+00	-4.2405E-03	0.0000E+00
7	6	14.000	11.667	-2.7546E+00	0.0000E+00	-1.5969E-07	-1.0482E-04	0.0000E+00	-3.1854E-03	0.0000E+00
7	7	14.000	14.000	-1.3602E+00	-1.3410E-16	1.6357E-04	1.8087E-05	-3.5371E-05	-5.2880E-01	4.0509E-17

ACCUMULATED FORCES FOR ROW 7, X = 14.00000

U	V	W	RU	RV	RW1	RW2
-1.6806E+01	-1.2410E-02	-7.5904E-05	1.2460E-04	1.1583E-05	0.0000E+00	4.7501E-03

CP SEC.= 42.990, I/O REQSTS.= 27, WORDS USED= 58496, WORDS TRANSFD.= 1.41653D+05

UNIT 1 (SHELL)

RESULTANTS

STEP 0

PA = 0.1000E+01
PE = 0.1000E+01

- - - - LINEAR SOLUTION - - - -

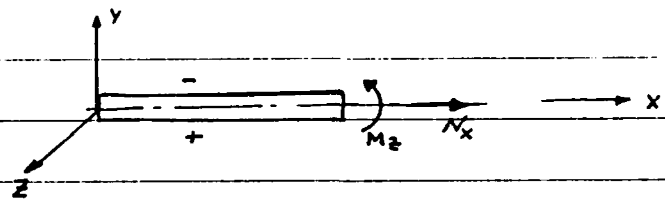
SKIN

ELEMENT ROW	ELEMENT COL	REF. SURFACE COORDS X	REF. SURFACE COORDS Y	FORCE RESULTANTS NX	FORCE RESULTANTS NY	FORCE RESULTANTS NXY	MOMENT RESULTANTS MX	MOMENT RESULTANTS MY	MOMENT RESULTANTS MXY
1	1	1.167	1.167	-0.1112E+01	0.3598E-01	0.7002E-01	-0.1152E-04	-0.9324E-05	-0.8268E-04
1	2	1.167	3.500	-0.1235E+01	-0.5069E-01	-0.1329E+02	0.3262E-05	0.7534E-05	-0.5199E-04
1	3	1.167	5.833	-0.1257E+01	-0.7817E-01	0.1043E-01	0.1242E-04	0.2122E-04	-0.9236E-05
1	4	1.167	8.167	-0.1219E+01	-0.9826E-01	0.9620E-02	0.1569E-04	0.2482E-04	0.3442E-04
1	5	1.167	10.500	-0.1354E+01	-0.1347E+00	0.5953E-01	0.1220E-04	0.1816E-04	0.5960E-04
1	6	1.167	12.833	-0.1026E+01	-0.7691E-01	-0.1773E+00	0.1086E-04	0.1027E-04	0.6175E-04
2	1	3.500	1.167	-0.1126E+01	-0.3204E-01	0.1197E+00	0.3756E-05	0.6706E-05	-0.5399E-04
2	2	3.500	3.500	-0.1237E+01	-0.2867E-02	0.5955E-01	0.2725E-04	0.3553E-04	-0.5024E-04
2	3	3.500	5.833	-0.1253E+01	-0.1340E-01	0.2912E-01	0.4716E-04	0.7396E-04	-0.1425E-04
2	4	3.500	8.167	-0.1264E+01	-0.1218E-01	0.1524E-01	0.5039E-04	0.7422E-04	0.3931E-04
2	5	3.500	10.500	-0.1276E+01	0.3465E-01	-0.1926E-01	0.3707E-04	0.4146E-04	0.6281E-04
2	6	3.500	12.833	-0.1047E+01	0.7408E-01	-0.1228E+00	0.1811E-04	0.1283E-04	0.6195E-04
3	1	5.833	1.167	-0.1165E+01	-0.2011E-01	0.3799E-01	0.1878E-04	0.1631E-04	-0.1012E-04
3	2	5.833	3.500	-0.1222E+01	0.4786E-02	0.4145E-01	0.6553E-04	0.5951E-04	-0.1363E-04
3	3	5.833	5.833	-0.1247E+01	0.1725E-01	0.2344E-01	0.1407E-03	0.1621E-03	0.7350E-05
3	4	5.833	8.167	-0.1252E+01	0.3134E-01	-0.4091E-02	0.1414E-03	0.1615E-03	0.4157E-04
3	5	5.833	10.500	-0.1214E+01	0.4587E-01	-0.4321E-01	0.6750E-04	0.6055E-04	0.4147E-04
3	6	5.833	12.833	-0.1104E+01	-0.1434E-01	-0.5657E-01	0.2377E-04	0.1850E-04	0.3658E-04
4	1	8.167	1.167	-0.1190E+01	-0.4483E-02	0.2151E-01	0.2377E-04	0.1850E-04	0.3658E-04
4	2	8.167	3.500	-0.1217E+01	0.1272E-01	0.2379E-01	0.6750E-04	0.6055E-04	0.4147E-04
4	3	8.167	5.833	-0.1232E+01	0.2583E-01	0.1155E-01	0.1414E-03	0.1615E-03	0.4157E-04
4	4	8.167	8.167	-0.1228E+01	0.3186E-01	-0.9895E-02	0.1407E-03	0.1621E-03	0.7350E-05
4	5	8.167	10.500	-0.1195E+01	0.2461E-01	-0.2931E-01	0.6553E-04	0.5951E-04	-0.1363E-04
4	6	8.167	12.833	-0.1141E+01	0.1308E-01	-0.2933E-01	0.1878E-04	0.1631E-04	-0.1012E-04
5	1	10.500	1.167	-0.1202E+01	0.7868E-02	0.8251E-02	0.1811E-04	0.1283E-04	0.6195E-04
5	2	10.500	3.500	-0.1215E+01	0.1701E-01	0.1036E-01	0.3707E-04	0.4146E-04	0.6281E-04
5	3	10.500	5.833	-0.1221E+01	0.2484E-01	0.3753E-02	0.5039E-04	0.7422E-04	0.3931E-04
5	4	10.500	8.167	-0.1212E+01	0.2555E-01	-0.7777E-02	0.4716E-04	0.7396E-04	-0.1425E-04
5	5	10.500	10.500	-0.1190E+01	0.1707E-01	-0.1656E-01	0.2725E-04	0.3553E-04	-0.5024E-04
5	6	10.500	12.833	-0.1162E+01	0.1072E-02	-0.1275E-01	0.3756E-05	0.6706E-05	-0.5399E-04
6	1	12.833	1.167	-0.1207E+01	0.1279E-01	0.2164E-02	0.1086E-04	0.1027E-04	0.6175E-04

UNIT 1 (SHELL)   RESULTANTS   STEP 0

SKIN

ELEMENT ROW	COL	REF. SURFACE COORDS X	Y	FORCE RESULTANTS NX	NY	NXY	MOMENT RESULTANTS MX	MY	MXY
6	2	12.833	3.500	-0.1214E+01	0.1904E-01	0.2463E-02	0.1220E-04	0.1816E-04	0.5960E-04
6	3	12.833	5.833	-0.1215E+01	0.2365E-01	0.6129E-03	0.1569E-04	0.2482E-04	0.3442E-04
6	4	12.833	8.167	-0.1206E+01	0.2170E-01	-0.2485E-02	0.1242E-04	0.2122E-04	-0.9236E-05
6	5	12.833	10.500	-0.1188E+01	0.1255E-01	-0.4556E-02	0.3262E-05	0.7539E-05	-0.5199E-04
6	6	12.833	12.833	-0.1172E+01	0.3014E-02	-0.3517E-02	-0.1152E-04	-0.9324E-05	-0.8268E-04



$(\sigma_{AVE})_x = \frac{N_x}{t}$, t = total thickness

etc.

```
BEGIN NON-LINEAR ITERATIONS FOR LOAD STEP    1,   PA=  0.1000000E+01,    PB=  0.1000000E+01,   THERMAL LOAD=  0.0000000E+00

ITERATION     RESIDUAL      DISPLACEMENT      RELAXATION        MAXIMUM         VARIABLE        STRAIN
               ERROR           ERROR            FACTOR          RESIDUAL         NUMBER         ENERGY
    1      0.909394E-06    0.290676E-01     0.100000E+01     0.148193E-04       208        0.420157E-03
    2      0.120843E-06    0.237893E-02     0.100000E+01     0.232487E-05       208        0.420159E-03
```

Residual Force Error — Displacement — Don't worry about this — Node w. maximum out of balance Force — Strain Energy associated w. displacement error

```
CONVERGENCE HAS BEEN OBTAINED FOR LOAD STEP   1
CP SEC.=   53.370,  I/O REQSTS.=      27,  WORDS USED=     58496,  WORDS TRANSFD.=    1.416530+05
CP SEC.=   53.430,  I/O REQSTS.=      29,  WORDS USED=     58496,  WORDS TRANSFD.=    1.456530+05
ORDER  0 EXTRAPOLATION WILL BE USED FOR LOAD STEP   2

MASS STORAGE FILE  2,  LENGTH   857,  COPIED TO TAPE 22      2 RECORDS,  510 WORDS PER RECORD
---------------------------------------------------------------------------------------------------------
- -  DISPLACEMENT SOLUTION WRITTEN ON SOC FILE (TAPE 22) FOR PA =   0.100000E+01,  PB =   0.100000E+01, - - STEP    1
---------------------------------------------------------------------------------------------------------
```

~~Result~~ not important

UNIT 1 (SHELL)

DISPLACEMENTS

Nonlinear solution includes large displacement Matrix

STEP 1

PA = 0.1000E+01
PB = 0.1000E+01

Rest of load steps will only increment PA since max PB is 2.0

ROW	COL	X	Y	U	V	W	RU	RV	RW1	RW2
1	1	0.000	0.000	5.0000E-05	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	3.0911E-05	
1	2	0.000	2.333	5.0000E-05	3.5148E-06	0.0000E+00	0.0000E+00	-3.5895E-06	1.6400E-05	-2.4051E-06
1	3	0.000	4.667	5.0000E-05	5.0248E-06	0.0000E+00	0.0000E+00	-5.4929E-06	7.2076E-06	-3.2582E-07
1	4	0.000	7.000	5.0000E-05	6.4816E-06	0.0000E+00	0.0000E+00	-5.8656E-06	9.4976E-07	1.2244E-06
1	5	0.000	9.333	5.0000E-05	9.5229E-06	0.0000E+00	0.0000E+00	-4.4002E-06	-6.7938E-06	-2.0766E-06
1	6	0.000	11.667	5.0000E-05	6.6483E-06	0.0000E+00	0.0000E+00	-2.1392E-06	-1.3355E-05	1.1474E-05
1	7	0.000	14.000	5.0000E-05	1.8585E-05	0.0000E+00	0.0000E+00	0.0000E+00	-4.5728E-05	-1.6464E-05

ROW	COL	X	Y	U	V	W	RU	RV	RW1	RW2
2	1	2.333	0.000	3.6027E-05	0.0000E+00	0.0000E+00	3.6265E-06	0.0000E+00	2.7210E-06	
2	2	2.333	2.333	4.0058E-05	2.2179E-06	7.4842E-06	2.7853E-06	-2.8252E-06	5.7278E-06	-8.3416E-07
2	3	2.333	4.667	4.1144E-05	4.6712E-06	1.2361E-05	1.3985E-06	-5.1163E-06	3.7022E-06	-1.2087E-07
2	4	2.333	7.000	4.1437E-05	7.0260E-06	1.3531E-05	-4.3800E-07	-5.7266E-06	6.0786E-07	3.7071E-07
2	5	2.333	9.333	4.1112E-05	9.4165E-06	1.0743E-05	-1.9229E-06	-4.8014E-06	-2.3992E-06	6.5715E-07
2	6	2.333	11.667	3.9568E-05	1.1619E-05	5.5260E-06	-2.5364E-06	-2.5936E-06	-3.5763E-06	3.0837E-06
2	7	2.333	14.000	3.1794E-05	1.3540E-05	0.0000E+00	-2.1935E-06	0.0000E+00	3.8593E-06	2.3576E-06

ROW	COL	X	Y	U	V	W	RU	RV	RW1	RW2
3	1	4.667	0.000	3.1327E-05	0.0000E+00	0.0000E+00	5.6367E-06	0.0000E+00	4.6605E-06	
3	2	4.667	2.333	3.1979E-05	2.2840E-06	1.2585E-05	5.1433E-06	-1.5352E-06	2.8159E-06	-2.7845E-07
3	3	4.667	4.667	3.2624E-05	4.7989E-06	2.2666E-05	3.4761E-06	-3.6817E-06	1.7144E-06	1.7280E-08
3	4	4.667	7.000	3.2845E-05	7.4522E-06	2.6233E-05	-4.7190E-07	-5.1438E-06	4.3557E-07	3.7736E-07
3	5	4.667	9.333	3.2457E-05	1.0233E-05	2.1098E-05	-3.8731E-06	-4.0581E-06	-7.9362E-07	7.9157E-07
3	6	4.667	11.667	3.1283E-05	1.3082E-05	1.0940E-05	-4.8132E-06	-2.0373E-06	-1.8916E-06	1.3268E-06
3	7	4.667	14.000	3.0425E-05	1.5946E-05	0.0000E+00	-4.5543E-06	0.0000E+00	-5.8062E-06	-8.4661E-07

ROW	COL	X	Y	U	V	W	RU	RV	RW1	RW2
4	1	7.000	0.000	2.3418E-05	0.0000E+00	0.0000E+00	6.0679E-06	0.0000E+00	1.2114E-06	
4	2	7.000	2.333	2.3950E-05	2.4036E-06	1.3875E-05	5.8144E-06	4.5520E-07	1.2188E-06	-5.8430E-08
4	3	7.000	4.667	2.4312E-05	5.0051E-06	2.6454E-05	4.9465E-06	4.8749E-07	8.1199E-07	1.0587E-07
4	4	7.000	7.000	2.4396E-05	7.7461E-06	3.2305E-05	-2.5692E-09	9.0154E-09	3.0661E-07	3.5222E-07
4	5	7.000	9.333	2.4045E-05	1.0540E-05	2.6446E-05	-4.9481E-06	-4.7054E-07	-1.9887E-07	5.9034E-07
4	6	7.000	11.667	2.3314E-05	1.3209E-05	1.3869E-05	-5.8113E-06	-4.4410E-07	-6.7245E-07	7.2451E-07
4	7	7.000	14.000	2.2229E-05	1.5589E-05	0.0000E+00	-6.0658E-06	0.0000E+00	-1.6778E-07	6.6004E-07

ROW	COL	X	Y	U	V	W	RU	RV	RW1	RW2
5	1	9.333	0.000	1.5834E-05	0.0000E+00	0.0000E+00	4.5463E-06	0.0000E+00	7.8349E-07	
5	2	9.333	2.333	1.5993E-05	2.5381E-06	1.0927E-05	4.8098E-06	2.0425E-06	5.9208E-07	1.3490E-08
5	3	9.333	4.667	1.6145E-05	5.1735E-06	2.1077E-05	3.8698E-06	4.0655E-06	4.0226E-07	1.4128E-07
5	4	9.333	7.000	1.6149E-05	7.8951E-06	2.6202E-05	4.6695E-07	5.1515E-06	1.8462E-07	3.1844E-07
5	5	9.333	9.333	1.5922E-05	1.0620E-05	2.2629E-05	-3.4768E-06	3.6895E-06	-5.0035E-08	4.7857E-07

REST OF OUTPUT NOT INCLUDED HERE.

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